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BIOLOGICAL AND PHYSICAL FEATURES OF KEALAKEKUA BAY, HAWAII

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BOTANY DEPARTMENT, UNIVERSITY OF HAWAII

FINAL REPORT

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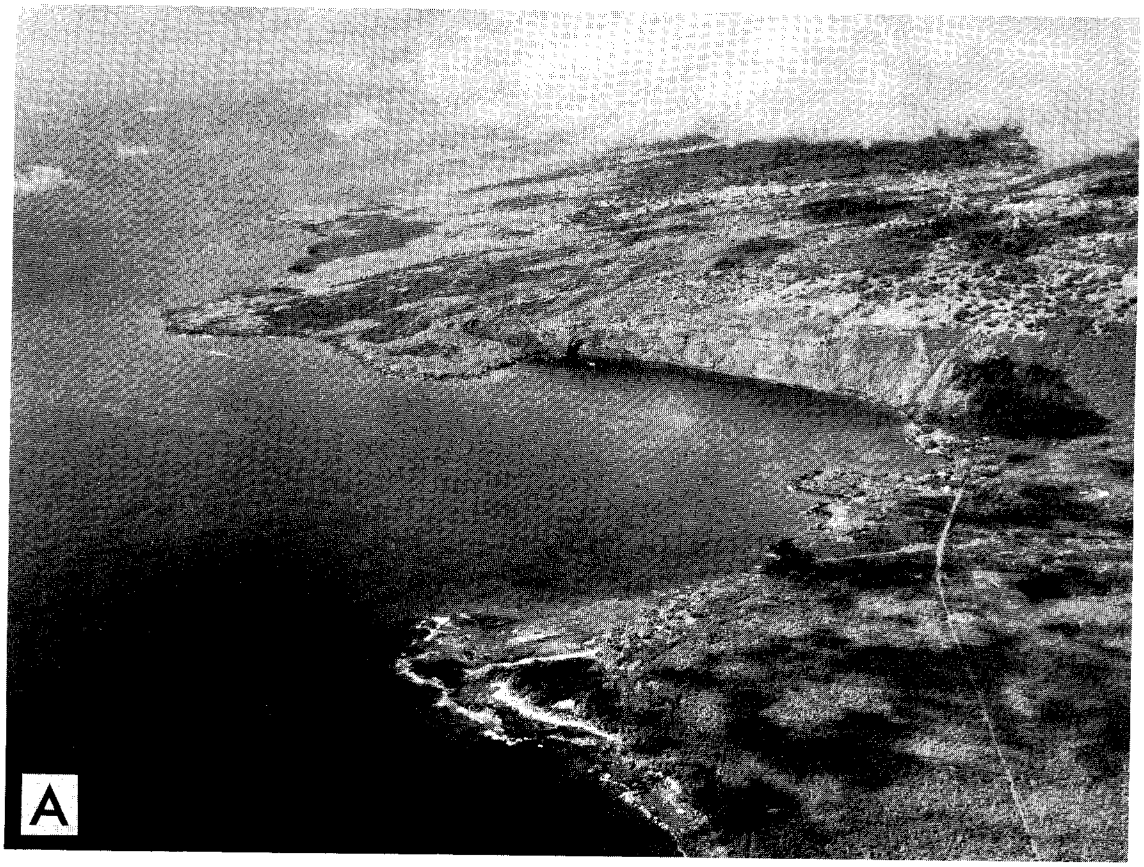
FIGURE A. Kealakekua Bay looking approximately north. Palemano Point appears at the bottom, Cook Point directly above, and further to the left is Keawekaheka Point. The village of Napoopoo lies on the north end of the conspicuous roadway on the right side of the figure. Kaawaloa Cove lies to the right of Cook Point.

FIGURE B. Kealakekua Bay looking southeast. Keawekaheka Point extends past the bottom edge of the figure. Cook Point appears centrally. Kaawaloa Flat covers the low area in the middle foreground. Napoopoo village can be seen on the opposite shore of the bay.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FOREWORD

"Once upon a time" man freely took whatever he desired from the environment. About 10,000 years ago a trend was initiated from such dependence upon the harvesting of the wild to dependence upon domesticated crops. As a result, private rights to property and its produce became established and resources became classified as useful, waste or wild. This describes in the most general terms the trend characterizing the development of man's present-day attitudes toward his environmental resources.

Today it is recognized that it is the yield of man's renewable resources that will determine, ultimately, the size at which the population of any independent political unit must become stabilized. Renewable resources are those that can be harvested and yet continue to yield at some sustained production rate——a property generally restricted to living systems. The limits of maximum sustained yield are being approached for the renewable resources of the land classified as useful, and man is being forced to exploit areas formerly considered waste or wild, including those of the sea.

With the explosive increase in human populations, the view that wild resources are "common property" for anyone and everyone to take must change. All resources, wild included, must be used to the optimal public benefit; benefit being defined to include esthetic, recreational, health, academic and commercial values and standards.

Public concern over problems of the classification and use of land areas under the pressures of expanding populations has been great, whereas apathy and neglect have been typical of the public attitude towards use of the sea. Concern has been reserved chiefly for single purpose usages of shallow waters such as for harbors, resorts, marine parks or for waste disposal.

In Hawaii most of the protected accessible shore areas have been greatly altered in recent time. Therefore, it is critical that the few remaining in a relatively pristine condition be studied to determine their real value beyond that which is readily apparent. Much information is required in order to plan for the maximum long-term multiple usage of a marine area, and as bays and other usable sea areas are rare in Hawaii, multiple purpose use must be considered.

As a start toward accumulation of knowledge critical to the assessment of the long-term and multiple use values of the State's shore areas, the State of Hawaii engendered a study of Kealakekua Bay, an undeveloped and apparently rather undisturbed marine site. The resulting data as compiled to December, 1968, are presented in the following text along with a summary of the major scientific results and conclusions. This information is essential to the State's planning for the development and use of Kealakekua Bay to the optimal benefit of the people of Hawaii.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

INTRODUCTION

This report has been prepared for the Office of the Lieutenant Governor of the State of Hawaii, pursuant to Purchase Order LG67-311, and agreement of June 1, 1968. The work was coordinated in the Botany Department of the University of Hawaii through the Research Corporation of the University of Hawaii.

Kealakekua Bay is located (19° 29' N; 155° 56' W) on the Kona (leeward) Coast of the Island of Hawaii. It lies on the western slope of Mauna Loa, approximately 4.5 miles south of the edge of Haulalai Volcano. A report (Soehren & Newman, 1968) preceding the present study was concerned with the archaeology of this region. The information included in the present text was provided by a specially constituted advisory group whose studies of Kealakekua Bay were organized around the following areas of investigation:

a- geography and physical nature;

b- hydrography, the chemical and physical nature of the water;

c- interrelationships between the land and sea at the present time;

d- distribution of the predominant and critical organisms;

e- interpretation of the populations of selected indicator and other organisms of particular interest, including:

seaweeds (limu),
plankton,
corals,
molluscs (sea shells, etc.),
crustacea (kona crabs, etc.),
echinoderms (sea urchins, etc.),
fish (developed from the State Division of Fish and Game monitoring program);

f- predictions of general conditions that can be expected to come to prevail with different low and high intensity uses;

g- recommendations toward providing a better and even more reliable understanding of the bay, and how it may be used maximally to benefit the public. These recommendations would include continued monitoring of the various indicative marine populations.

The extent of investigation was from Keawekaheka Point just north of Kealakekua Bay to Palemano Point at the southern end of the bay. However, for comparative purposes some material presented here concerns Honaunau Bay, located 1.5 miles south of Kealakekua Bay at the City of Refuge National Historical Park, and other areas.

As this study progressed it became clear that Kealakekua Bay was unusual in several respects, and this induced some alteration of the initial plans. For instance, due to the inconspicuous role played by algae, bivalve molluscs and crustacea in the bay, little work was done with these organisms. When one regards the general character of the bay, it is not surprising to find these, respectively, high inorganic fertilizer utilizers and detritus feeders inconspicuous. Emphasis was increased accordingly on the showpieces of Kealakekua Bay, the corals, vertebrates, gastropod molluscs and echinoderms.

The people who have contributed a great deal of time and effort to gathering and presenting the information in the following chapters form an impressive list. First, Mr. Fred Weld who, acting as assistant to the compiler, did most of the leg work and gathered the little and some not so little pieces of data, which included doing all the field work not otherwise undertaken. He has also put together the different manuscript sections as obtained from the various contributors.

The chapters are presented without specific author citations, as the contributions often overlapped, most authors making a good many contributions outside their own area of specific interests. The principal authors and collaborators and their major field of contribution, for which the compiler is extremely grateful, are as follows:

Dr. Thomas A. Ebert (sea urchins), Department of Zoology, University of Hawaii.

Dr. John R. Hendrickson (turtles, sharks and porpoises), The Oceanic Foundation, Makapuu Point, Oahu, Hawaii.

Dr. Alison E. Kay (molluscs), Department of General Science, University of Hawaii.

Dr. Charles H. Lamoureux (vascular plants), Department of Botany, University of Hawaii.

Dr. Sidney J. Townsley (corals), Department of Zoology, University of Hawaii.

In addition to the above, several faculty members of the University of Hawaii served as advisors, often visiting Kealakekua Bay to facilitate the process. These include Prof. Vernon Brock, Hawaii Institute of Marine Biology; Dr. Philip Helfrich, Hawaii Institute of Marine Biology; and Dr. John A. Maciolek, Department of Zoology.

The material concerning geological features was mostly written by Dr. Gordon A. Macdonald, Department of Geosciences, University of Hawaii. Much of the material on underwater topography was contributed by Mr. Mark M. Littler, Department of Botany, University of Hawaii; and by Dr. Michael Neushul, Department of Botany, University of California at Santa Barbara. Mr. Donald Kelso, Department of Zoology, University of Hawaii, was a heavy contributor to Chapter 7.

Mr. Michio Takata receives our special thanks for directing the fish populations be monitored, an activity which could well be extended

to the other groups of dominant organisms. For similar reasons appreciation is expressed to Dr. Kingston S. Wilcox, Department of Health, State of Hawaii, who made the microbiological assays available, and to Prof. Stephen L. Lau, Department of Civil Engineering, for similar assistance with the chemical analyses. Dr. Joseph Branham, Department of Zoology, University of Hawaii, aided in much of the early research for Chapter 9.

The aerial photographs comprising the frontispiece are published by the courtesy of Dr. Agatin T. Abbott, Department of Geosciences, University of Hawaii. Dr. Abbott kindly contributed several other aerial photographs of the region which were used in the study. Gratitude is expressed to Mrs. Barbara Downs who prepared the art work for Chapter 9; to Mrs. Diane Littler who assisted in field and art work for the shoreline vegetation, and to Mr. Terry Powell who also contributed art work.

Local residents of the area were most helpful, and the following as research assistants facilitated the gathering of the information presented in the individual chapters: Messrs. L. E. Bishop, E. Brecknock, E. Guinther, J. McVey, B. Miller and S. Swerdloff. Persons specifically aiding Mr. Sakuda (and sometimes Mr. Kenji Ego) in the Fish and Game surveys include Messrs. T. Fujimura, R. Kanayama, P. Kawamoto, E. Onizuka and C. Vares.

To the end that Kealakekua Bay becomes used maximally to the benefit of the people of Hawaii, the compiler wishes to express his appreciation to the above and to the farsightedness of the State officials who have encouraged the making of this study.

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REPORT AND CONCLUSIONS

Kealakekua Bay, a mile-wide bay on the Kona Coast of Hawaii, has been a nucleus of activity throughout recorded history. It presents a largely "pristine" atmosphere as little evidence of human exploitation is visible. The circumnavigator, Captain Cook, twice visited the bay and met his death at Kaawaloa, a Hawaiian village presently in ruins at the north end of the bay.

Today, two tourist vessels each with a capacity for 120 persons make daily excursions to the bay from the resort area of Kailua-Kona. The principal interest is the monument to Captain Cook set amid "unspoiled" surroundings of kiawe. A glass-bottom boat is moored nearby, and life jackets are provided for tourists wishing to swim. On the return trip to Kailua, the tourist vessels swing by Hikiau Heiau (Fig. 4) on the bay by Napoopoo Beach Park. Here, a costumed "Kahuna" briefly ceremonializes for their benefit. The City of Refuge National Historical Park is one and one-half miles south.

The conclusions of the present study of Kealakekua Bay relate to the geological and hydrological conditions and to the algae (limu), plankton, corals, molluscs (e.g., sea shells), sea urchins (vana), crustacea (e.g., lobsters, crabs, shrimp), fish, porpoises, turtles and the surrounding land mass vegetations. Ecological zones are described for both land and marine populations, and land-sea relationships are discussed in terms of the sediment and other contents of the freshwater runoff.

No thermocline, or layering of large water masses, was detected above a depth of 400 feet. The current along this part of the Kona Coast flows southward most of the year. During a falling tide the upper meter of water inside the bay flows (Fig. 5) in the same general direction as the southerly offshore current. However, during a rising tide the movement is strongly towards shore (Fig. 6) with Manini Beach Point and Palemano Point acting to direct the water in two broad circular patterns, from Napoopoo to Kaawaloa Cove and from Palemano Point to Kahauloa Cove, respectively.

The current along the shoreline is hence reversed for rising and falling tide situations. To illustrate this, one morning several years ago a house floated into the bay near Napoopoo. It floated along the pali face to Cook's Monument, but then began drifting back the way it came. That evening it beached near where it had washed out at Napoopoo.

The speed of the current along the face of the pali is 50 m/hr (2 ft/min) compared with 500 m/hr outside of the bay, a difference of one order of magnitude. Although nothing of a quantitative nature regarding "flushing times" of water masses was undertaken, the preliminary work does indicate that material entering along the periphery of the bay would disseminate comparatively slowly into the bay proper due to the speed and reversing nature of the current. As the offshore current is generally southerly, south-facing Kaawaloa Cove is more sheltered from the influences of offshore winds and currents than are other regions of Kealakekua Bay. It is in this area that the Napoopoo fishing vessels are moored for the winter.

Experimental shark fishing was conducted in Kealakekua Bay from a line stretched overnight from Cook Point to Palemano Point. Six sharks were taken, and the shark population was termed moderate for the bay. The sharks were all taken off either Palemano Point or Manini Beach Point, and this in keeping with current data as sharks are known to swim "upstream" in foraging.

A major consideration in this study was in locating and testing points of freshwater seepage into the bay. No river mouths or estuarine situations are present, but the amount of brackish water, even measured after a prolonged dry period, is considerable.

"Brackish water" here refers to percolation into the bay of runoff water from the surrounding land masses; its volume reflects the water table. The higher ground surrounding Kealakekua Bay receives much more rainfall than does the bay itself.

In a brackish situation the colder, less dense fresh water forms a layer over the sea water. This layer varies with the tide height, the rate fresh water percolates into the area and the rate of diffusion. The rate of mixing in a sheltered area such as Kaawaloa Cove, for example, is much slower than off the more exposed Keei.

Twenty-two brackish stations were established and described within the confines of Kealakekua Bay. The major brackish areas (Fig. 7) are at Kaawaloa Cove, Napoopoo, Kahauloa Cove and by T. Ashihara's cottage. At these four stations a brackish layer several feet in thickness extends several hundred feet into the bay when the tide is near its ebb.

Brackish water was detected off the caves at Keawekaheka Point, by the end of the jeep road to Kaawaloa Flat, off Cook's Monument and off Umi's Well in Kaawaloa Cove. As was indicated above in discussing currents, Kaawaloa Cove is comparatively sheltered due to its southern exposure. The rate of percolation from the region of Umi's Well is greater than in any other sheltered locality of the bay excepting Kahauloa Cove. At these two stations, a brackish layer of varying thickness more or less permanently blankets the surrounding sea water.

As the sheltering slows diffusion rates of the seeping ground water and its mineral and organic constituents, it is felt that this area by Cook's Monument would be particularly vulnerable to alterations in the nature of the freshwater runoff. Reasons for believing Kaawaloa Cove to presently be in delicate ecological balance are discussed below in the sections on coral and urchin communities.

The freshwater indicating seaweed genera, Ulva and Enteromorpha, grow off Umi's Well, and nearby a glass-bottom boat is moored which supports a luxurious garden of Ulva, the green sea lettuce.

Certain of the shells at Kaawaloa Cove are brackish-water species. These include the pipihis, Theodoxus neglectus and Planaxis labiosa, and the bivalves Pinctada margaritifera and Isognomon californicum.

Brackish water was found at six points (Fig. 7) between Kaawaloa Cove and the Napoopoo State dock, but the stations were localized and rates of percolation not high. Beyond the dock is a partially gravelly, boulder-strewn, crescent-shaped beach fronted by private homes. The entire beach at low tide acts as a sieve for fresh water, but although the rate is high the bay is less sheltered here than at Kaawaloa Cove, and the surface layer of brackish water is not nearly so prominent.

Beyond the above stations, fresh water enters the bay at regular intervals to the rocky promontory which begins Manini Beach Point. Further on is Kahauloa Cove which is strongly brackish and very protected. At nearly all tides a blanket of brackish water covers the entire inlet. South of that at T. Ashihara's cottage, the freshwater is also considerable, but the area is not protected and diffusion is rapid.

The shoreline south of this last station contains relatively far fewer brackish areas than does the region north. There is some freshwater percolation at the canoe landing near Manago's cottage, and some by the abandoned YMCA camp south of Palemano Point, and some more 600 m still further south of this at a fisherman's shanty, but no further stations were identified between there and Honaunau Bay. However, it was felt that brackish areas probably do exist, but the shoreline is highly exposed, and they were not detected by the methods employed in this survey.

Selected brackish stations were sampled for coliform and fecal coliform bacteria, and for total phosphorous and total nitrogen present in the water. The values obtained were then compared with the public health regulations of the State of Hawaii regarding water quality standards. The results of our survey indicate that the entire bay excepting Kaawaloa Cove and the populated region by the Napoopoo State dock meets the standards for "AA Waters," which is pristine and characteristic of a wilderness area. The other two areas meet the standards for "A Water," which, although not pristine, are considered completely suitable for swimming and recreational use.

The underwater topography of Kealakekua Bay was described. In general (Fig. 2), the shore drops off sharply beyond the ten-fathom line. At times this drop is quite precipitous. There seems to be very little coral or any other organisms growing on the steep outer slopes, and SCUBA divers noted a marked sterility at greater depths associated with the substrate which is generally sandy.

The general biotic picture then is one in which the vast bulk of the living organisms is concentrated along a shallow rim of the bay. This intensifies the intimacy of the relationship between the existing biota and conditions on the surrounding land masses, and means that marine plant and animal communities would in all likelihood be extremely responsive to any modifications.

In general near shore the bottom is covered with an assortment of boulders or smaller fragments, and these boulders are usually larger as one progresses seaward. In general the dominant recognizable organisms are coelenterate corals, fishes and sea urchins. Progressing seaward the coelenterate coral cover becomes denser. As the ten-fathom line is approached the individuals are thicker and they cover more nearly 100 per cent of the bottom.

The visible macroscopic algal material (limu) is almost entirely intertidal or on very shallow near-intertidal rocks. Except for spots of mat-like crusts of algae on boulders in some areas, *Turbinaria ornata* is the only macroscopic alga seen in water over two meters deep. There is a paucity of species such as *Sargassum* upon which turtles are known to feed.

It was felt that presently the worst example of habitat exploitation by man concerned bottom litter and that this condition was principally restricted to the area near Cook's Monument. There is an abundance of trash here, including auto tires, tin cans, rope, wire, bottles and the like. The only area showing evidence of human disturbance to the coral is also in Kaawaloa Cove. Hired divers break off coral for the tourists (this is advertised in the excursion brochures), and some spots have been badly mauled by anchors.

As indicated above, the benthic seaweed population is sparce; indeed, to the casual observer it might appear absent. No conspicuous beds are to be seen anywhere in Kealakekua Bay at the present time. However, the environment would appear suitable for heavy cover in some areas, such as in the southern reaches of the bay.

In Waikiki seaweeds occur in various quantities, and that they are hard to find in any quantity in Kealakekua Bay is related to low fertilizer concentrations. Although present now in only token amounts, the usual species complement for the rest of Hawaii can perhaps be found here.

Algal beds are often conspicuous in areas where fresh water and fertilizer are introduced. The luxurious mats of Ulva on the glass-bottom boat moored near Cook's Monument are noted above. A more familiar example is the splash of green in front of the bathhouse at Hanauma Bay on Oahu. The principal among these green pollution indicators is the presence of an algal community dominated by the genus Ulva, at present only an occasional alga at Kealakekua Bay. Large green areas of this sea lettuce, often becoming off-white or yellowish in part, could be expected to develop if a significant amount of fresh water and fertilizer were to percolate into the bay, or even if processed sewage were to be furnished.

The development of a pollution-type marine community in Kealakekua Bay would mean loss of much of the present Hawaiian marine life, and in few other areas is this marine life more readily accessible to the itinerant.

A marine shore area in balance suddenly receiving quantities of fertilizer flushed in with fresh water will alter in adapting to the new conditions. The expected pattern is for a series of near-irreversible changes to occur. The first changes to be seen are in the microscopic algal organisms, those essential to the larval animal stages and utilized (as zooxanthellae) by coral adults. The results are newly dominant species of the short-lived, frequently reproducing kinds. In this case, they will be those relatively insensitive to or stimulated by the addition of freshwater and the fertilizers derived from sewage. In the tropics these are usually members of the Ulvaceae; Enteromorpha if a steady supply of fresh water is involved, or Ulva if the fresh water is less or periodic and contains increased nitrogenous wastes. Thus, it is that a splash of green from these seaweeds in front of a residence or bathhouse indicates pollution.

An Ulva community is usually strangely devoid of animal life or much of any living material other than the seaweed Ulva itself. Many explanations have been offered for this, but wide variations in the oxygen content of the water and the production of toxic materials are two which do function to the exclusion of animals.

With the advent of sewage disposal in Kealakekua Bay and such populations as the above appearing, the natural food for the native organisms decreases. Thus, the fish and other animal populations would decrease to the extent they did not consume the new algal population or the pollution material directly.

Alteration of any natural habitat such as Kealakekua Bay will encourage success of exotics. This is the general explanation for the lack of native plant and animal life below about the 1500-foot level on Oahu. Exotic seaweed species such as Acanthophora spicifera, Ulva recticulata and Dictyosphaeria cavernosa have become dominating elements in Kaneohe Bay within the last 20 years accompanied by the disappearance of other, less tolerant seaweeds and of those fish species which had fed upon them.

New plantings on land are usually well watered and fertilized and most of that fertilizer percolates to the sea nearby. Even apart from the fertilizer, as the plants grow and photosynthesize much of that organic material may wash out of the plant into the ground water and, to the extent not destroyed by biological activity in the soil, end up in the sea along with the inorganic fertilizer materials.

Such a situation might be expected to develop upon introduction of a golf course. Here the volume of freshwater runoff would rise due to watering, and would be enhanced with fertilizer constituents and with vegetative material from the increased photosynthetic yield of a lush, grass cover.

If sewage effluent were to be introduced into the bay, it might have to be transported to considerable depths and employ diffuser techniques in order to avoid detrimental effects on the shallow water biota.

Tows were made for zooplankton (Fig. 14), and the area of the bay found most abundant in zooplankton was Kaawaloa Cove, near Cook's Monument. This further indicates its sheltered nature, that this water mass does not flush as rapidly as do other parts of the bay.

One conclusion of the coral studies done in Kealakekua Bay was that the population present is unique to this area. Seventeen species of coral in 13 genera were collected, one of which was a new record for Hawaii.

There is marked zonation of the coral with depth due to the steepness of the bay and its protection. Four distinct coral zones were distinguished in Kaawaloa Cove, for example, and the extent of their vertical distribution was thought limited by light penetration, temperature and possibly food. It was brought out that the species of coral present in this cove are presently in a very delicate ecological balance, a balance thought to be principally maintained by low phosphate in the environment, and by lowered salinity and temperature due to the presence of freshwater. Some corals do not tolerate high levels of phosphorous.

The most noteworthy feature of the marine molluscan fauna (sea shells, etc.) of Kealakekua Bay from the standpoint of general interest is its diversity, the densities exhibited by some species, and the occurrence of some of the more spectacular molluscs in relatively shallow water. These aspects are, of course, enhanced by the sparkling, clear waters and exceptional visibility usually experienced in the bay.

The conclusion is that in terms of species diversity, peculiarities in faunal composition, habitat differences and densities, the marine molluscs of Kealakekua Bay may very well be unparalleled in any other similarly circumscribed area in the Hawaiian Islands. In just walking around on the low ledge of Cook Point, for instance, over 40 species are exposed to view.

The diversity of marine molluscs here is probably associated with both the diversity of conditions and habitats found in the bay and with the unsilted waters. An area of approximately comparable habitat diversity but with silty water is Kaneohe Bay, Oahu. There, 110 marine molluscan species are now found compared with 184 in the much smaller Kealakekua Bay.

At the present time the vast number of sub-environments present is remarkable. There are for instance a surprising number of different, specialized sand communities, and both the densities and number of species in the sand communities in Kealakekua Bay appear to be higher than those of Oahu. In Kaneohe Bay, once again, the sand communities are comprised of about half as many molluscan species and the densities of each species is considerably less than that in Kealakekua Bay.

In terms of percentage composition of species, the proportion of gastropods (cowries, cones, etc.) to bivalves (clams, oysters, etc.) is 89:11 (or 89 per cent gastropods) in Kealakekua Bay. This appears to be higher than has been measured elsewhere in the Hawaiian Islands, which has an overall proportion of 82:18. The ratio in Kaneohe Bay, Oahu, is 80:20.

Bivalves are filter feeders and are hence considered pollution indicators, whereas a gastropod population is indicative of unsilted conditions. Hence, as an area becomes contaminated one expects the ratio to decrease by the appearance of large numbers of bivalves such as clams, and extinction of various gastropod species of cowries and cones. It is known that many gastropod species which used to be collected in Kaneohe Bay are no longer present, and the exceedingly high percentage for Kealakekua Bay is evidence for the unspoiled conditions that exist there.

It is felt that at the present time the mollusc population is in a delicate ecological balance and disturbances, such as increased nitrate and phosphate salts leaching into the bay, would result in an imbalance of the community and possible extinction of some species from the area.

Although, as noted above, the area around Cook Point is very rich in molluscs, their general density and diversity is greatest toward the opposite end of the bay. Palemano Point is considered the richest area, particularly so in abundance of larger shells. In certain areas of the bay, several workers noticed a paucity of some of the more showy shells.

By order of importance the major sea urchins of Kealakekua Bay are the slate pencil urchin, Heterocentrotus, and the vanas, Echinothrix, Echinometra and Tripneustes.

Probably the most striking aspect of the urchin population from a tourist standpoint is the rich abundance of colorful slate pencil urchins, often prized as souvenirs, and the spines of which are made into wind chimes for sale by local merchants. Indeed, this is the most abundant urchin species in Kealakekua Bay. It is particularly abundant in the region around Cook's Monument and, to a lesser extent, on the north side of Palemano Point. This great abundance of slate pencil urchins does make the area unique as other than along the Kona Coast and at a few sites on Maui such as Molikini Reef, Heterocentrotus is not common.

It was determined from secondary productivity rates that the turnover rate of Kealakekua Bay urchins is more than five years and probably close to ten years. This gives an indication of the rather long time it would take a community to repair itself if harvested or otherwise damaged.

The factors affecting distribution and abundance of urchins are often listed as depth, substrate, exposure to waves, food, animal behavior and chance. With these in mind the distribution and densities of urchin populations in several localities within Kealakekua Bay were plotted. However, the finding was that the urchin populations were correlated with none of the above measureable parimeters, and that chance probably played a major role in their establishment. What this means is that were the urchin community to be wiped out, in all likelihood something different would come back. The present, unique assemblages probably would not return.

In postulating chance as a major determining factor in urchin distribution it was noted in this study that certain features were not associated with physical or biological factors. For example, at Napoopoo Light, Echinothrix was the dominant urchin, yet this species was not present at a physically similar station one mile south of Honaunau Bay. Tripneustes was also different between these two stations and, as noted above, the slate pencil urchin, Heterocentrotus, is highly important in most sites examined along the Kona Coast yet is generally uncommon in other areas of the Hawaiian Island chain.

Whether Heterocentrotus has always been rare in other areas is not known for certain. Edmondson (1946) lists Tripneustes and Echinothrix as common forms and says that Heterocentrotus "frequents the outer border of the reef platform, but young specimens are sometimes seen near the shore." This applies mainly to Oahu. The impression is given by Edmondson that Heterocentrotus certainly has not been a dominant element of the urchin fauna for the past 70 years, if it ever was.

Echinometra oblonga was present in all shallow areas of Kealakekua Bay except Kaawaloa Cove. Here it was absent, but a similar vana, E. mathaei was common. The reason for this disparity is that the latter species grows only in sheltered habitats, the former in more exposed situations. It is concluded that being most sheltered, the region of Cook's Monument is the most vulnerable area of the bay to factors of pollution.

Urchins form a segment of the shallow water communities that probably receives a large portion of the energy from primary production by algae. The urchin population in Kaawaloa Cove does decrease with depth or darkness, so presumably its numbers do depend rather directly upon primary productivity.

Predictions of the results of human activities to the urchin fauna must naturally be very tentative. However, a number of most probable results can be suggested. First, anything that would tend to eliminate the living coral would probably change the species composition of Kaawaloa Cove. The most likely change would be reduction of Heterocentrotus and a possible increase of Tripneustes. With the associated decrease in bottom relief, Echinothrix would also be expected to decrease.

Effluent from sewage treatment plants would increase turbidity in the bay and, through light attenuation, would decrease productivity with depth. Such processes are known to cause sharper urchin zonation with fewer at lower depths. The net result would in all probability be an overall decrease in urchin biomass.

Because it presently is not known whether the abundance of Heterocentrotus on the Kona Coast represents an ecological climax situation (the result of many communities succeeding each other in ecological progression toward equilibrium), or is instead a community formed by factors of chance, the recovery of a bay after a marked biotic change is difficult to predict.

If the area is a climax community, it would probably return to its original state. On the other hand, if the species composition was established by chance, then severe damage would not necessarily be reparable. From the data presented in this study, it appears likely that chance is important.

The only larger crustacean seen in numbers was the "cleaning shrimp," Stenopus hispidus. Lobsters are scarce in Kealakekua Bay, but Kona crabs are trapped here in isolated groups on sandy-bottom stretches not frequented by fish.

Five underwater, 750-foot stainless steel transect lines were established in Kealakekua Bay (Fig. 32) over which fish counts were periodically made. It was determined (Tables 14 through 16) that Kealakekua Bay has 210 pounds of fish per acre and Honaunau Bay, 227 pounds. This is more than in Hanauma Bay, Oahu. Off Waikiki, by comparison, 148 pounds of fish per acre were counted. The highest fish density recorded in the Hawaiian Islands is on a transect placed off

Niihau. The mean count was 275 pounds per acre, and the region is considered pristine. However, it should be pointed out that this Niihau transect is located on a substrate particularly favorable for fish.

One hundred and ten different species of fishes were observed in Kealakekua Bay, 32 of which were common. The most common species are yellow tang (*Zebrasoma flavescens*) and kole (*Ctenochaetus strigosus*).

The pounds of fish per acre (Table 14) counted on individual transects in Kealakekua Bay ranged from 58 to 669, and it was felt the mean figure of 210 probably reflected a low bias as two of the five transects ran across sandy bottoms where very few fish occurred.

Another reason for supposing there might be more fish present in Kealakekua Bay than was recorded is that the majority of SCUBA divers surveying the length of the bay observed that the region of Palemano Point was considerably richer in abundance and diversity of fishes than was Cook Point. There was no transect located near Palemano Point, and the highest counts were recorded on transect lines set near Cook Point.

The sterility at greater depths was remarked on above, pointing out that the fish communities are concentrated along the shallow rim of Kealakekua Bay. Few are found in deep areas due to the steepness of the slope beyond ten fathoms, and the sandy substrate which, because of its paucity of fish food, does not support fish in numbers.

It was thought unwise from a conservation viewpoint to allow netting, trapping and spearfishing if Kealakekua Bay were to be established as a preserve. This would insure preservation of the present population integrity and approachability of inshore fishes. However, it was also thought that *at the present time* fishing and netting are on such a small scale that to prohibit these would not result in any

<u>increase</u> in the fish population, such as is presently being experienced in Hanauma Bay, Oahu, which previous to restrictive measures had been extensively fished.

With the knowledge that the region is presently subject to a human population influx, the time for protective measures is thought now, before undesirable changes from non-regulated exploitation of the environment, such as occurred in Hanauma Bay, have been wrought.

Kole (<u>Ctenochaetus strigosus</u>) is a common species of fish throughout the islands, whereas Hawaiian kole (<u>C. hawaiiensis</u>) is common in Kealakekua Bay, but uncommon in most areas of the Hawaiian Islands. These species live between boulders and coral mounds and feed on microorganisms. Just why the latter is common here is not known, and Kealakekua Bay might be an ideal place for studies of the origin and interaction of these two species.

A dearth of "turtle algae" was noted above, and indeed during a study period of several days, but three turtles were observed in Kealakekua Bay.

One of the more interesting aspects of Kealakekua Bay in terms of projected exploitation for tourism is the large school of resident spinner porpoises (<u>Stenella</u> sp.). From 30 to 80 members have been estimated, and the school is invariably present in some region of the bay, most often in the environs of Manini Beach Point. The porpoises are very tame, and follow boats for considerable distances with several members commonly playing in the bow wake.

Babies of less than 36 inches in length may be seen, and at least five sub-groups hanging together were distinguished in addition to "unattached" animals in the school. For studies of social organization and interaction this school might be superior to any wild school yet known.

The researcher most experienced with porpoises and their domestication has never before seen spinner porpoises so casual about being closely approached, and feels they could constitute a remarkable asset to the local tourist industry. Regarding semi-domestication and training in the wild, as has been proposed for resident schools elsewhere, it would be simply a matter of applying routine training techniques to establish a "hold" over them, and then progress to such displays as jumping *en masse* on sound signal, or following a particular boat in jumping trains.

Such animals could also be trained to accept coordination and endurance routines for various physiological tests and other scientific activities. This use would not necessarily interfere with the hypothetical tourist show.

As indicated above, there is an intimate relationship between a shoreline and conditions on nearby land masses. Land use is reflected in the nature of the freshwater runoff, which in turn reflects on the marine biota subjected to it. For this reason, a study was undertaken of the present vegetation types on the land surrounding Kealakekua Bay.

Fourteen vegetation types (Figs. 38 through 40) were recognized and described from Keawekaheka Point to Honaunau Bay. These range from open lava flows to pastureland mixed with remnant native forest to Kiawe forests.

Throughout the region the vegetation predominantly consists of species introduced to Hawaii since the time of Captain Cook. The only part of the region where plants that were present in Hawaii at the time of Cook's arrival are at all common is on the open lava flows on and mauka of Kaawaloa Flat. Also, just mauka of the coffee mill and north of the plumeria plantation, on a fairly open lava flow, are several trees of ohe makai (Reynoldsia sandwicensis), a rare endemic tree. This is perhaps the botanically most interesting plant now to be found in the entire region surveyed.

There appears no compelling botanical reason for preserving the vegetation of the area in its present state, but if in connection with archeological projects it seems desirable to re-create an area as it appeared in pre-Cook times, Kaawaloa Flat and Kaawaloa Village would seem the logical place to do this. Some of the botanically more interesting plants persisting in this area are listed on Table 17 . Kaawaloa Village today is covered with a kiawe forest. The kiawe was brought to Hawaii in 1828. In 1778 Kaawaloa Village probably contained mainly coconut trees, with some kou (a few are still present near Cook's Monument), milo and noni.

Pua-pilo (Capparis sandwichiana), an endemic shrub, dominates some areas of Kaawaloa Flat. It is more abundant here than has been observed anywhere else on the major Hawaiian Islands. Both shrub and postrate forms were observed, often growing side by side. This phenomenon has not been observed elsewhere.

A recreation of the pre-European scene has been undertaken at the City of Refuge with some success. However, the City of Refuge project has involved the use of herbicides, and caution should be exercised whenever large doses of herbicides are employed to avoid permanent buildups of residues in the soil, and especially to avoid runoff into Kealakekua Bay where significant ecological changes might occur. Mechanical means of weed control are preferred whenever feasible.

Chapter 1

GEOLOGY

(Physical nature of the region)

Kealakekua Bay lies (Fig. 1) on the western slope of Mauna Loa, approximately 4-1/2 miles south of the edge of Hualalai Volcano. Mauna Loa is an active volcano, which erupted last in 1950, when three lava flows descended the western slope of the mountain and entered the ocean. The northernmost of the lava flows reached the sea 9 miles south of Kealakekua Bay.

As indicated by Figures A and B of the Frontispiece, Kealakekua Bay is hardly a landlocked harbor. However, there is adequate protection in the region of Napoopoo for small boats against moderate storms from different directions, and during the heavier, winter storms these boats are safely moored at Kaawaloa Cove.

The various maps and profiles included in this report were taken from Coast and Geodetic Survey Charts, U. S. Geological Survey Charts, Army Map Service Maps and from aerial photographs. The basic maps and charts are discussed in the following chapter, and are readily available from a variety of sources, including Trans-Pacific Instrument Company, 1406 Colburn, Honolulu, and the U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California.

Aerial photographs are particularly useful in studies such as the present one. Most of the commercial Honolulu aerial photography concerns (listed under Photographers-Aerial in the yellow pages) have sets or access to sets of these photographs, and they may be purchased from the Aerial Photography Division of the Agricultural Stabilization and

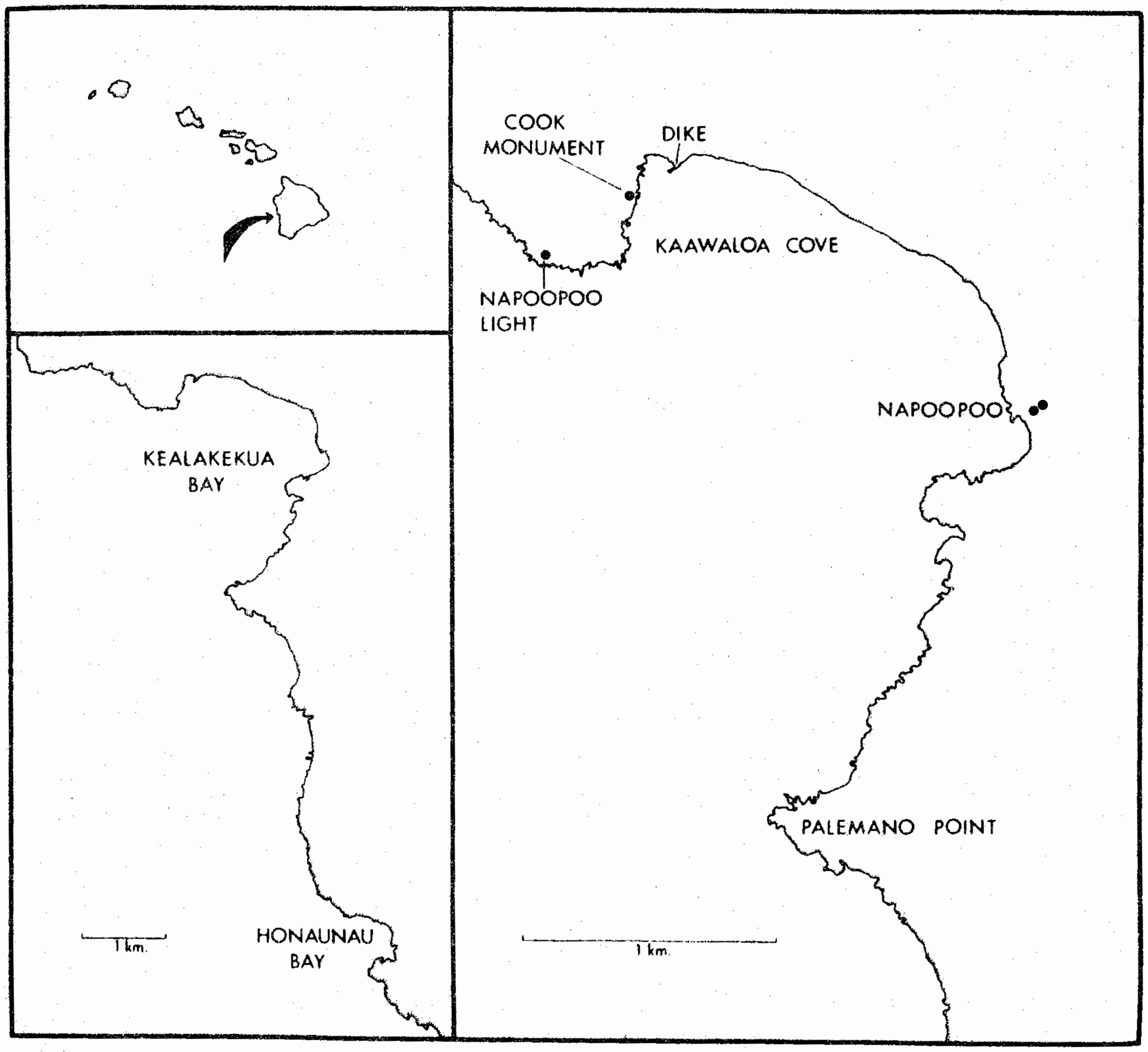


FIGURE 1. Outline of Kealakekua Bay and environs indicating its position in the Hawaiian chain.

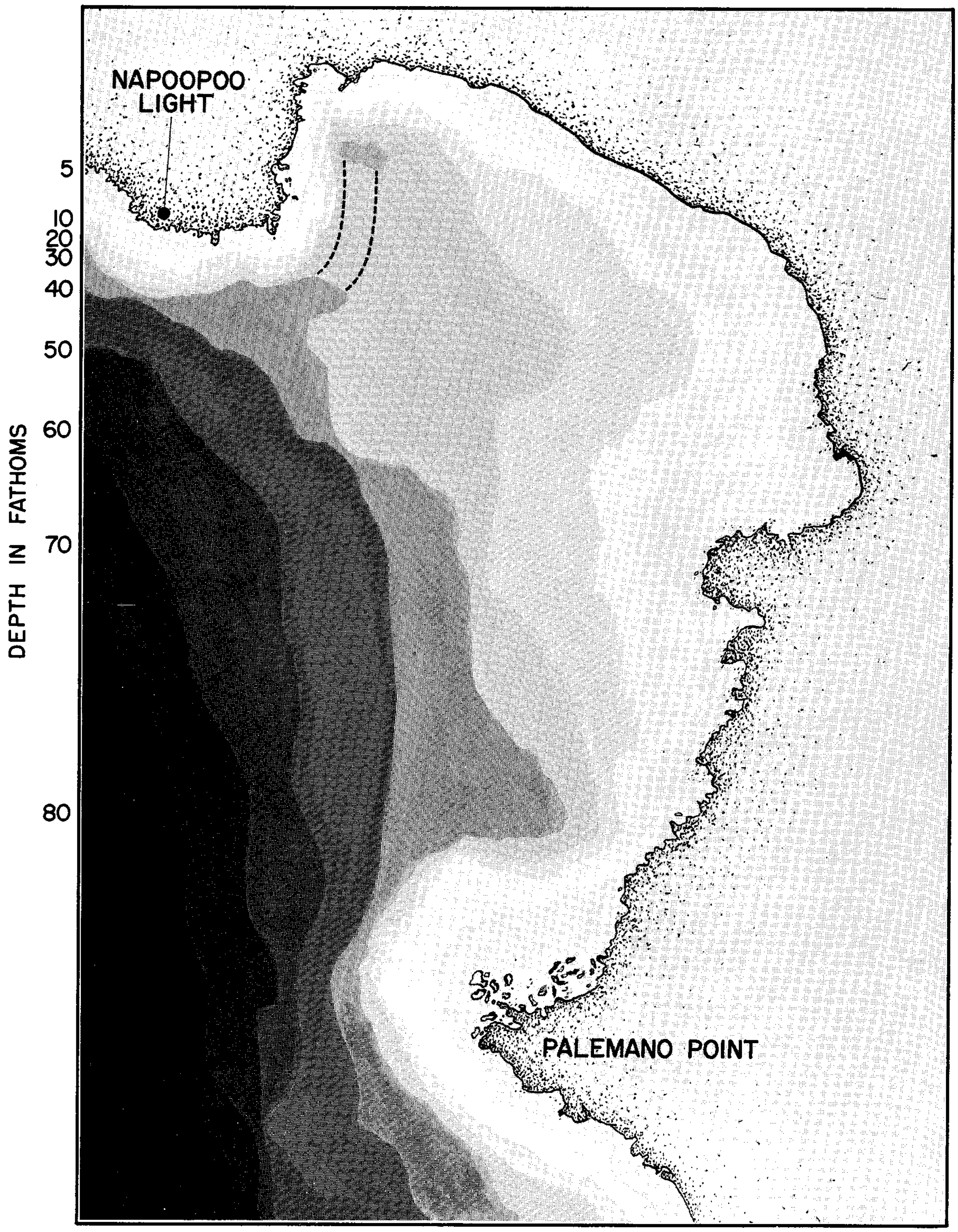
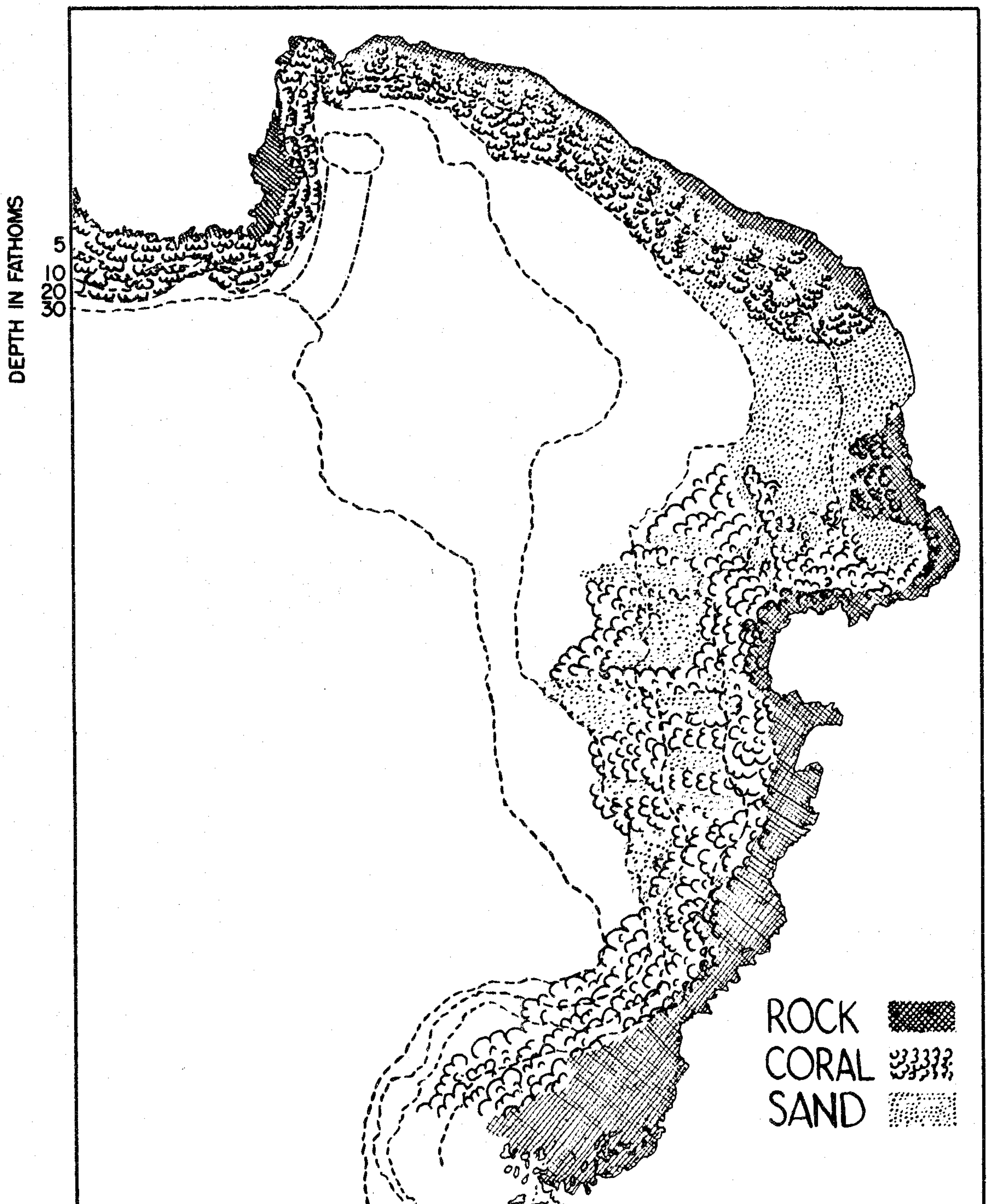


FIGURE 2. A chart of Kealakekua Bay showing depth contours in fathoms. Data derived from USC&GS chart 4123 (1967). Contour lines approximated from soundings.

FIGURE 3. A schematic chart of Kealakekua Bay showing dominant bottom types to depths of approximately 100 feet. Four general zones are noted. The area of Cook Point is typified by a narrow basalt shelf extending out to a shelf of dense coral which drops off sharply. Only small pockets of sand are found in this region. The inshore zone at the base of the pali is typified by a narrow band of basaltic boulders and fingers of coral on a hard base interspersed with patches of sand. In the area of Napoopoo village is an extensive sand patch. It runs outward and spreads both north and south from a black sand beach just north of Hikiau Heiau. The region from Manini Beach to Palemano Point consists of a basaltic shelf of varying widths with extensive coral growth interspersed with large patches of sand. This chart merely serves to indicate general zones of bottom type rather than specify exact boundaries of these areas.


DEPTH IN FATHOMS
5
10
20
30
ROCK
CORAL
SAND

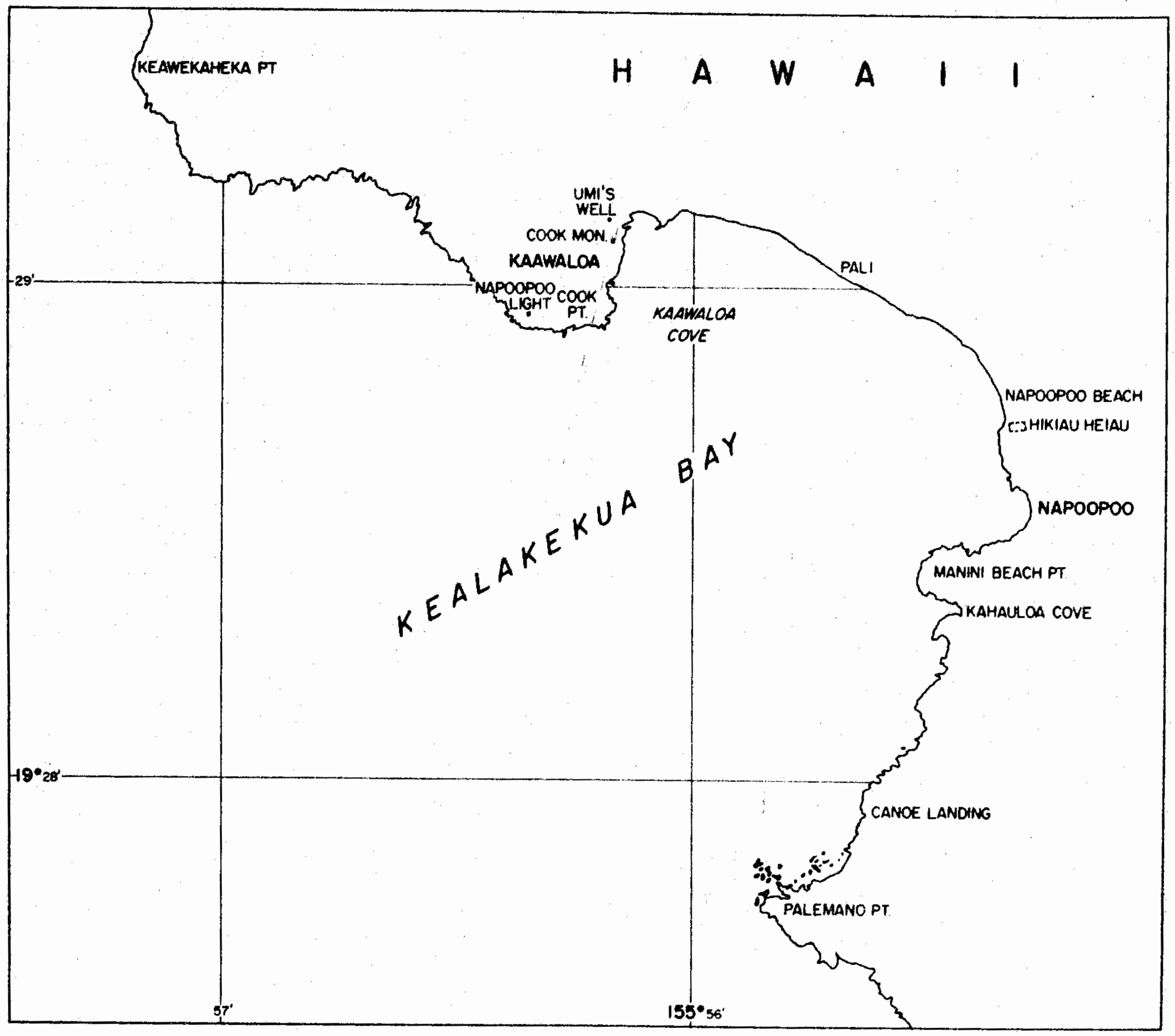


FIGURE 4. Profile of Kealakekua Bay with the place names used in this survey.

Conservation Service, U. S. D. A., 2505 Parley's Way, Salt Lake City, Utah. Aerial photographs of various specifications are also filed by the Land Study Bureau, University of Hawaii, and by the Earth Sciences Department, Hawaii Institute of Geophysics, University of Hawaii. Figures A and B of the Frontispiece were attained from this last source, and are published through the courtesy of Dr. Agatin T. Abbott.

The western slope of Mauna Loa consists of innumerable thin flows of basalt lava. North of the northernmost flow of 1950 all of the lavas are prehistoric, though they are of Recent geologic age. Both pahoehoe and aa types are present. The aa flows have rough clinkery surfaces, and often clinkery bottoms, with relatively dense massive central portions. The pahoehoe flows have smooth, billowy or wrinkled ("ropy") surfaces. They commonly contain lava tubes, which are the open pipe-like channelways through which liquid lava moved to feed the front of the flow when it was active. At the end of the eruption a decrease in the supply commonly allows the liquid to drain out of the channelway, leaving the pipe-like tube open. The lava flows formed layers generally between 5 and 20 feet thick which slope seaward over most of the western flank of the volcano at an angle of about 10° from the horizontal.

Near sea level the western slope of Mauna Loa is broken by several faults, on which the portion of the volcano seaward of the fault has moved downward relative to that on the landward side. The faults are not single fractures, but groups of subparallel fractures known as fault systems. Two fault systems affect the area near Kealakekua Bay. The Kaholo fault system lies close to the shoreline from a point just south of Honaunau southward for 15 miles or more, to the vicinity of Milolii. Offset on the produced a seaward-facing cliff (fault scarp) that lies 1/4 to 1/2 mile inland from the shoreline. It has been mantled by lava flows from the upper slope of Mauna Loa. The cascades and draperies of lava along the buried fault scarp are well displayed just south of the ancient City of Refuge at Honaunau. The City of Refuge itself lies on a coastal flat built by a pahoehoe lava flow that spread out below the scarp.

The Kealakekua fault system is a series of faults that trend southeastward along the northeastern side of Kealakekua Bay. One of the faults extends west-northwestward beneath the ocean. Movement on it produced the earthquake that caused extensive damage in Kona in August, 1951. Another fault extends northwestward from the head of the bay, and is responsible for the steep escarpment at the inland edge of the flat area just north of the bay on which the village of Kaawaloa formerly was located, and on which the Cook Monument now stands. North of the bay the fault scarp has been buried by later lava flows, and these flows, spreading out beyond the scarp, built the flat, which terminates at Keawakaheka Point.

The same fault formed the scarp at the northwestern edge of Kealakekua Bay. There the scarp has not been buried by lava flows, and has been only slightly trimmed back by wave and subaerial erosion. In it there are exposed the edges of many thin lava flows that are older than the fault scarp. The pahoehoe flows contain lava tubes, clearly visible in the cliff, some of which were used as burial sites in prehistoric and early historic times. Near the base of the cliff is a layer of yellowish volcanic ash, 6 to 20 inches thick. The lavas beneath this ash bed are the only ones in the area that may be older than Recent in geologic age. They may possibly be of late Pleistocene age.

The faults of the Kealakekua system extend southeastward from the head of the bay for about 3 miles, then bend southward and disappear beneath younger lava flows, although the abnormally steep slope indicates that they probably continue southward beneath the lava cover for at least 4 miles more. Lava flows moving downslope over the fault scarp have spread out beyond it to form the broad gently-sloping apron that borders the coast between Kealakekua Bay and Honaunau. The Keei Battlefield is located on this flat.

Three miles north of Kealakekua Bay, at the coast, Puu Ohau is a small cinder cone probably formed by steam explosions where a lava flow entered the sea.

The only historic eruption within the area took place beneath the ocean in 1877. At that time (February 24, 1877) steam and fragments of lava rose along a west-northwest-trending fissure in Kealakekua Bay and for a mile or so farther out to sea. A continuation of the crack is said (H. M. Whitney, 1877) to have extended inland nearly 3 miles, and clouds of steam and smoke issued from the fissure either in that area or farther up the mountainside (Westervelt, 1916). The eruption was preceded by a severe earthquake.

Chapter 2

CURRENTS

Measurements of the current system in Kealakekua Bay were undertaken on two occasions. On 27-X-68, the current during a falling tide was measured, and six days later the measurements were repeated in a rising tide.

Only movement in the upper meter of water was measured. The wind was easterly, and absent to moderate. Wind resistance, however, was not determined.

Eleven current meters of a modified Drogue-buoy design were constructed and tested in the field. They consisted of partially submerged aluminum floats supporting a wooden "X" frame. The frame was hung at a depth of one meter, held vertical by basalt weights, and was made of four 10-by-10-inch-square boards nailed to a center post at right angles with one another.

The current outside of the bay was southerly at all times, and was strong (500 m/hr). Local fishermen indicated that during most of the year the current outside the bay remains southerly. Along the periphery of the bay, movement in the upper meter drops to 50 m/hr, which is a difference from beyond the bay of one order of magnitude.

During a falling tide (Fig. 5) the current through the bay remains generally southerly. The movement along the shore is from Kaawaloa Cove toward Napoopoo. Manini Beach Point[1/] acts to fork the

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1/ Manini Beach Point (Fig. 4) is the name local residents give this low, rock promontory. Its north face is labeled Manini Beach on USGS map 5106 (1959).

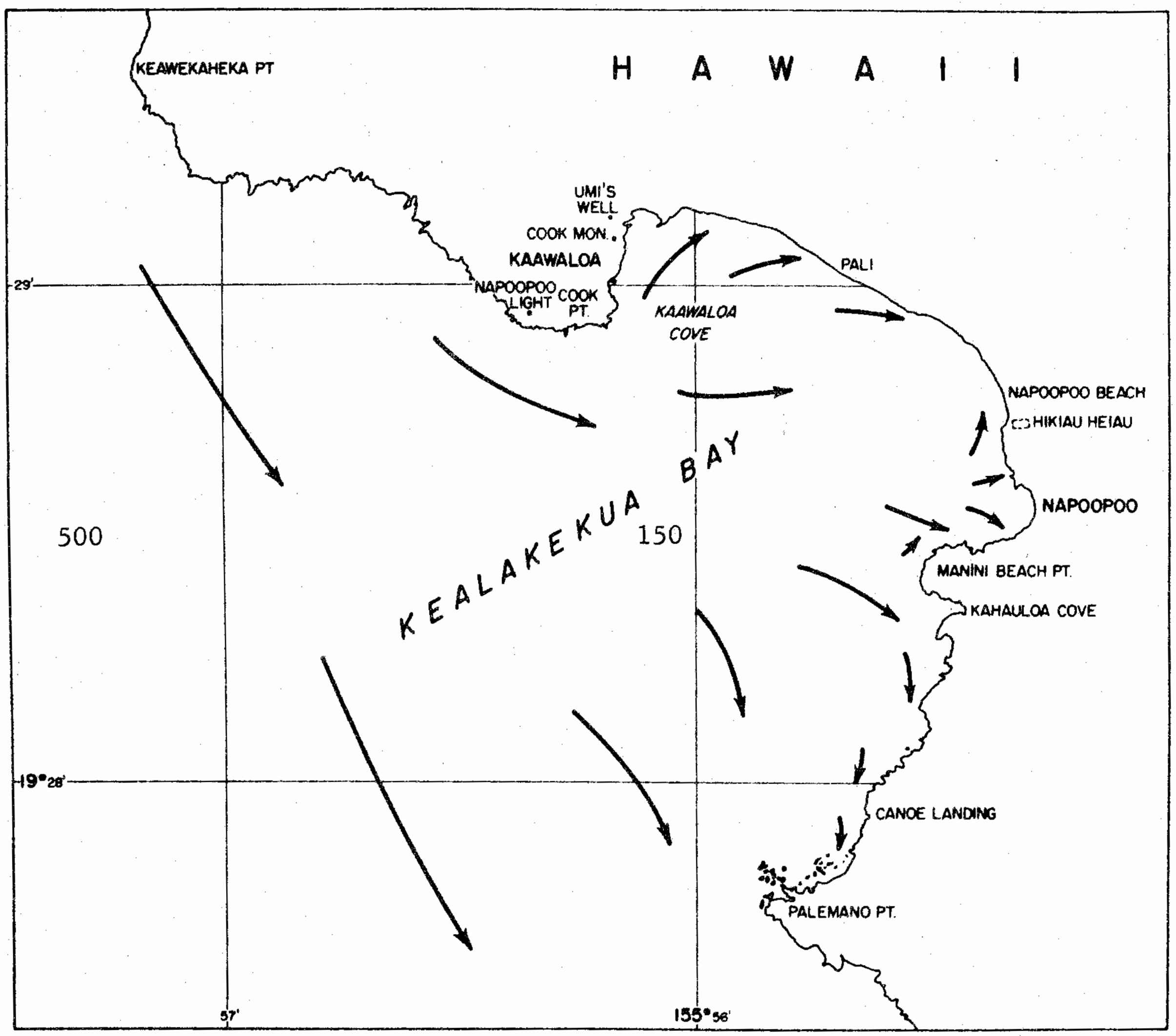


FIGURE 5. Movement of the upper meter of water during a falling tide. The length of the arrows is proportional with the speed of the current, and the numbers refer to meters per hour as measured in different parts of the bay.

water mass into westerly and easterly directions. Directly off the point movement is nil, but water approaching along the bay side of the point is directed eastward toward Napoopoo. The current meters then beach along the strip of land from Manini Beach to the State dock. The current meters directed west around Manini Beach Point are either carried around Palemano Point[2] anywhere from Ashihara's cottage[3] to south of Manago's cottage[3].

Movement during a rising tide (Fig. 6) is strikingly different. Manini Beach Point continues to divide the current toward Napoopoo or toward Palemano Point, but now two broad circular patterns of water movement are established. Palemano Point directs water back along the shoreline toward Manini Beach Point, where it flows offshore and southward again toward Palemano Point.

A similar situation occurs between Napoopoo and Kaawaloa Cove. The movement is westward along the face of the pali, from Napoopoo towards Cook's Monument. The current meters are then directed toward Cook Point and swept again southward, back toward Napoopoo.

Hence in a falling tide the upper meter of water moves eastward along the pali face, and in a rising tide the direction is westward.

2/ Palemano Point (Fig. 4) is known as Keei Point by local residents, and its north face as Keei Beach. USGS map 5106 (1959) also labels the north face Keei Beach, and the general region, Keei. However, USC&GS chart 4123 (1967) indicates Keei is the region of Manini Beach Point.

3/ Extensive use as landmarks is made in this report of Ashihara's cottage and Manago's cottage (Fig. 4). The former is a private residence owned by T. Ashihara of Kealakekua, and the latter is a rental unit maintained by Manago Hotel, Captain Cook.

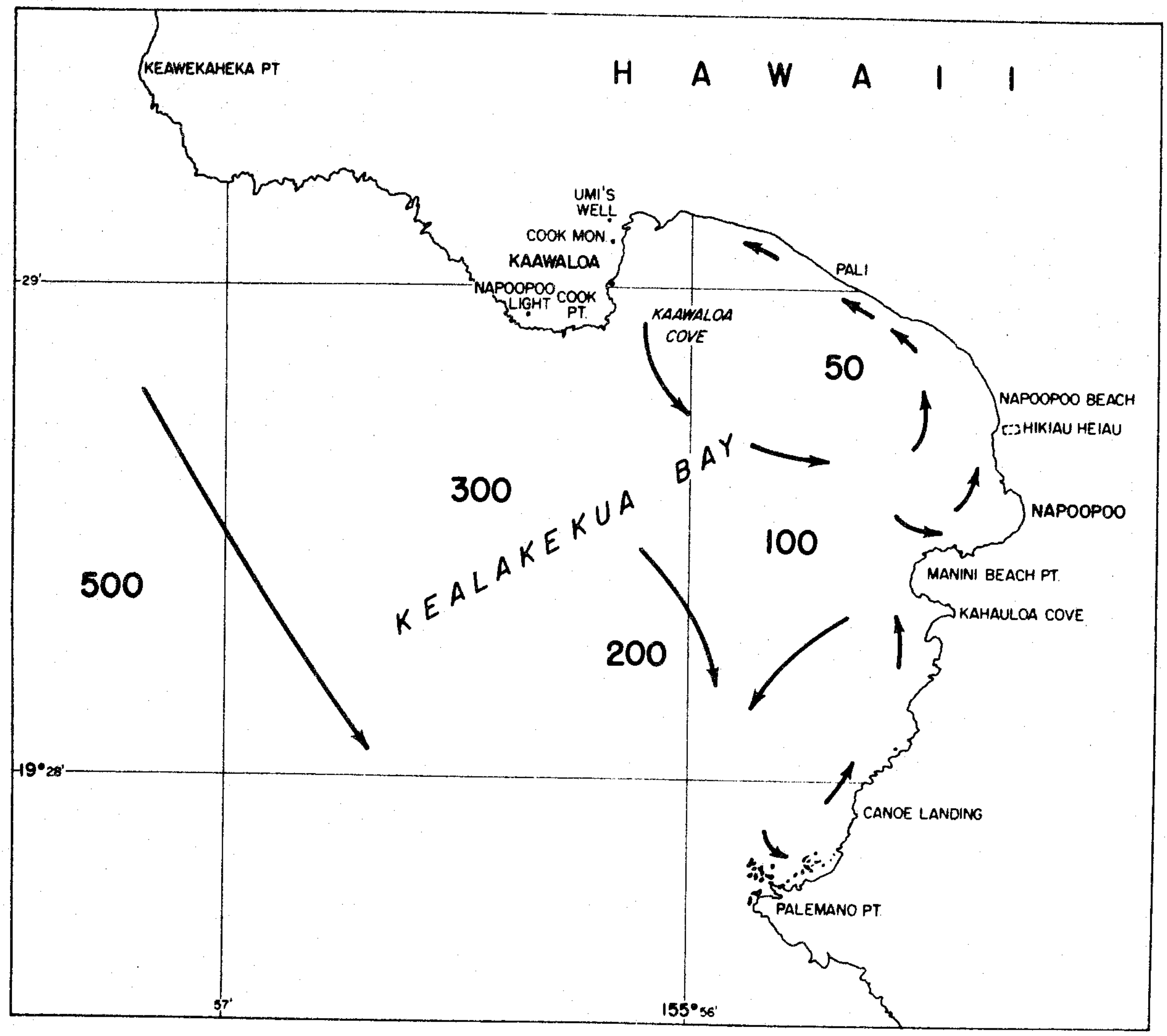


FIGURE 6. Movement of the upper meter of water during a rising tide.

In discussing these results with local fishermen, it was recalled that several years ago a house floated into the bay at Napoopoo, and that morning was carried along the face of the pali to Cook's Monument in Kaawaloa Cove. In the afternoon, however, it began floating in the opposite direction, and that evening beached at Napoopoo near where it had originally washed into the bay.

Owing to a possible sheltered condition that exists in parts of Kealakekua Bay, particularly in Kaawaloa Cove, and to the slowness and reversing nature of the currents in these areas, it was considered unfortunate that refined studies could not at this time be undertaken to gauge flushing times for the various parts of the bay. The study completed, however, does appear to emphasize a sheltered condition of the bay, particularly in regard to the northern reaches.

Chapter 3

BRACKISH WATERS

The shoreline from Keawekaheka Point to Loa Point, one mile south of Honaunau Bay, was surveyed for brackish water. Testing was of salinity as shown on a hand refractometer, lowered temperature and refractive disturbance in the water as noted with a view box or face mask. There had been no rain for several weeks prior to sampling, and most of the sampling was done near ebb tide when the freshwater lenses, or layers of fresh water on top of the surrounding sea water, are at a maximum. No streams empty into Kealakekua Bay.

"Brackish water" in this chapter refers specifically to percolation into the bay of runoff water from the surrounding land masses; its volume reflects the water table. The higher ground surrounding Kealakekua Bay receives much more rainfall than does the bay itself.

The entire periphery of Kealakekua Bay was surveyed for brackish water by foot, save impassible areas which were swum. However, the regions north of Cook Point and south of Palemano Point were generally sampled exclusively by boat. It was felt that due to the extreme exposure of these areas, some brackish spots probably exist which were not detectable by the methods used in this survey.

A total of 29 discrete brackish stations (Fig. 7) were located and plotted, and 22 of these stations are concentrated within the confines of Kealakekua Bay.

The majority of stations were sampled of several occasions, at various tide heights, and with results (Table 1) often dissimilar due to

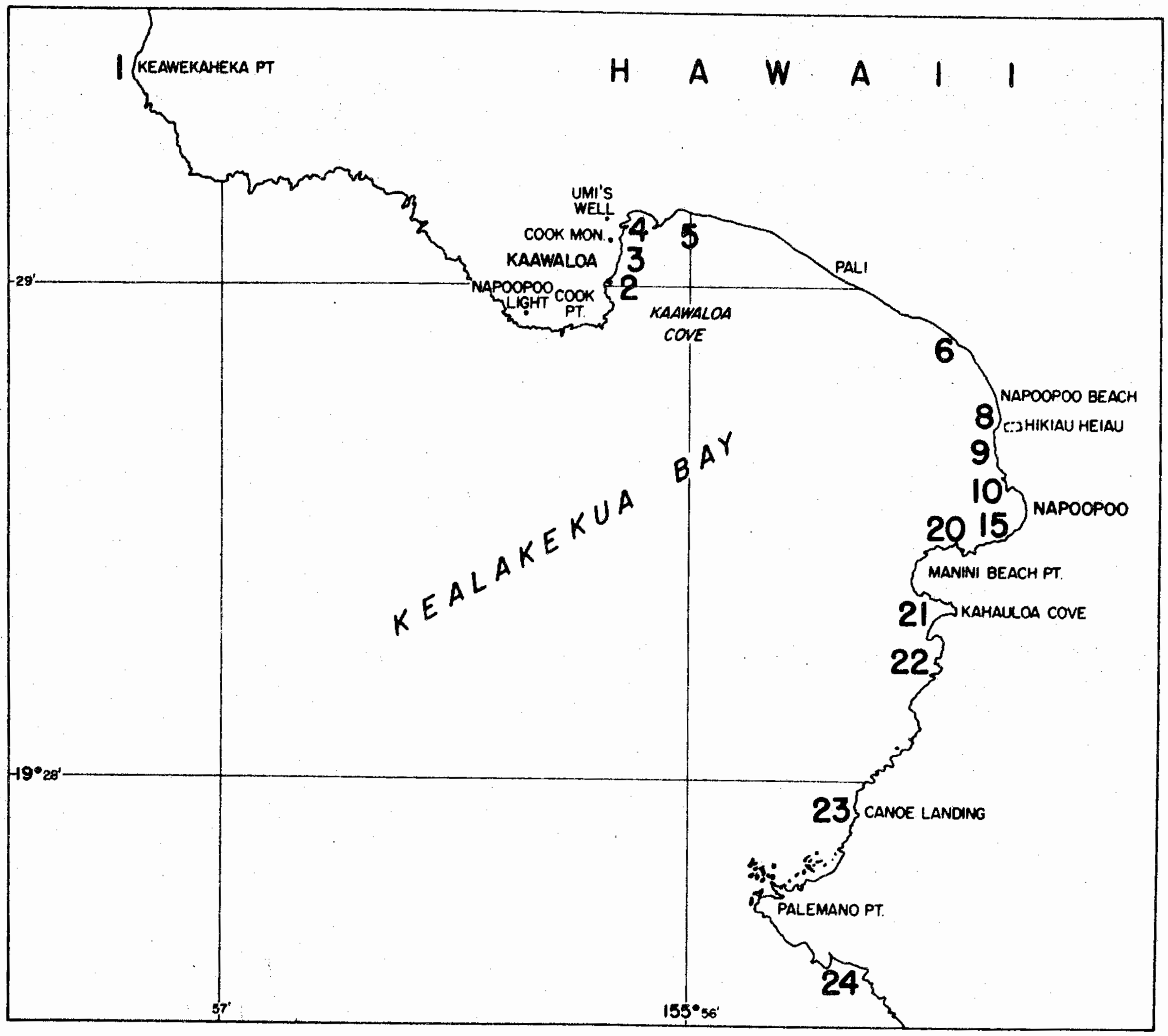


FIGURE 7. Areas in which brackish water is concentrated.

TABLE 1. Brackish water characteristics.

Station no.	Time	Tide	Description	Salinity (ppt)	°C	Standard plate count per ml	Mpn coliform per 100 ml	Mpn fecal coliform per 100 ml	µg-at/l nitrate	µg/l nitrate	µg-at/l phosphate	µg/l phosphate
1	26-X-68		10 m out, surface	32.0								
2	1115 18-X-68	+0.6 rising	shore, surface	24.0								
			shore, 10 m north	32.0								
			shore, 10 m south	33.0								
	0900 29-X-68	+1.5 rising	shore, surface	26.0	27.5	1,200	700	700				
3	6-VI-68		shore, surface	17.3					24.70	345.74	1.43	44.42
			bottom, 1 m depth	34.0					2.48	34.69	0.21	6.42
	6-VI-68		1 m depth	5.0					35.44	496.14	2.80	86.88
4	1600 27-X-68	+0.3 ebb	shore, surface	16.0	24.0							

TABLE 1 (continued)

Station no.	Time	Tide	Description	Salinity (ppt)	°C	Standard plate count per ml	Mpn coliform per 100 ml	Mpn fecal coliform per 100 ml	µg-at/l nitrate	µg/l nitrate	µg-at/l phosphate	µg/l phosphate
4			10 m out, surface	21.0	26.0							
			10 m out, bottom	34.0	27.0							
			30 m out, surface	28.0	26.5							
	0900 29-X-68	+1.5 rising	shore, surface	22.0	26.0	520	2,400+	2,400+				
			shore, 10 m east	30.0	27.0	230	2,400+	Negative				
			20 m out, 1/4 m depth	32.0	27.5	50	240	62				
			20 m out, 1 m depth	34.5	28.0							
5	12-X-68		shore, surface	24.7					17.24	243.32	1.27	39.25
			bottom, 1 m depth	25.9					3.75	52.50	0.31	9.61
	1000 28-X-68	+2.1 flood	shore, surface	32.0	28.0							
			10 m out, surface	32.0	28.0							
			10 m out, 1/2 m depth	34.0	28.0							

TABLE 1 (continued)

Station no.	Time	Tide	Description	Salinity (ppt)	°C	Standard plate count per ml	Mpn coliform per 100 ml	Mpn fecal coliform per 100 ml	µg-at/l nitrate	µg/l nitrate	µg-at/l phosphate	µg/l phosphate
5	0900 29-X-68	+1.5 rising	shore, surface	34.5	28.0	290	Negative	Negative				
6	12-VI-68		shore, surface	10.5					2.25	31.56	0.34	10.60
			bottom, 1 m depth	27.2					4.37	61.12	0.26	7.91
	1750 28-X-68	+0.2 ebb	shore, 3 m east	26.0	27.0							
7	13-VI-68		surface	7.4					1.99	27.85	4.86	150.57
			1/2 m depth	6.2					1.69	23.67	2.63	81.47
8	13-VI-68		shore, surface	21.0					3.15	44.09	0.46	14.32
			bottom, 1.5 m depth	36.8					2.45	34.31	0.22	6.67
	1750 28-X-68	+0.2 ebb	shore, surface	32.0	27.5							
9	1750 28-X-68	+0.2 ebb	shore, surface	2.0	21.0							
	0800 29-X-68	+1.3 rising	shore, surface	20.0	24.5	2,700	2,400+	2,400+				
10	1630 28-X-68	+0.5 falling	shore, surface	4.0	22.0							
	0800 29-X-68	+1.3 rising	shore, surface	30.5	26.5	120	Negative	Negative				

TABLE 1 (continued)

Station no.	Time	Tide	Description	Salinity (ppt)	°C	Standard plate count per ml	Mpn coliform per 100 ml	Mpn fecal coliform per 100 ml	µg-at/l nitrate	µg/l nitrate	µg-at/l phosphate	µg/l phosphate
11	13-VI-68		surface	22.2					32.82	459.45	1.32	40.98
			bottom	40.7					1.59	22.32	0.18	5.43
	1600 28-X-68	+0.5 falling	surface	24.0	25.5							
			1.3 m depth	28.0	27.0							
	0830 29-X-68	+1.4 rising	surface	30.0	26.5	10	13	6				
12	1700 28-X-68	+0.3 ebb	shore, surface	14.0								
			shore, 10 m south	20.0								
13	1700 28-X-68	+0.3 ebb	shore, surface	3.0								
			shore, 10 m south	18.0								
14	1700 28-X-68	+0.3 ebb	shore, surface	2.0								
			shore, 10 m north	15.0								
			shore, 10 m south	22.0								
	0800 29-X-68	+1.3 rising	shore, surface	25.0	26.5	100	Negative	Negative				
15	1700 28-X-68	+0.3 ebb	shore, surface	8.0								
			shore, 10 m north	18.0								
			shore, 10 m south	26.0								

TABLE 1 (continued)

Station no.	Time	Tide	Description	Salinity (ppt)	°C	Standard plate count per ml	Mpn coliform per 100 ml	Mpn fecal coliform per 100 ml	µg-at/l nitrate	µg/l nitrate	µg-at/l phosphate	µg/l phosphate
16	1700 28-X-68	+0.3 ebb	shore, surface	10.0								
			shore, 10 m north	24.0								
			shore, 10 m south	22.0								
17	1700 28-X-68	+0.3 ebb	shore, surface	14.0								
	0800 29-X-68	+1.3 rising	shore, surface	25.0	26.5	30	210	Negative				
18	1630 28-X-68	+0.5 falling	shore, surface	3.0	20.0							
	0730 29-X-68	+1.2 rising	shore, surface	8.5	23.0	400	2,400+	23				
19	1600 28-X-68	+0.5 falling	shore, surface	22.0	26.5							
20	13-VI-68		shore, surface	17.3					22.81	319.30	1.70	52.58
			bottom, 1 m depth	24.1					4.84	67.76	0.57	17.52
	0930 27-X-68	+0.7 rising	50 m out, surface	34.0	27.5							
			50 m out, bottom (1.5m)	34.5	28.0							
	0730 29-X-68	+1.2 rising	shore, surface	18.0	23.0	90	700	62				
	1815 29-X-68	+0.3 ebb	shore, surface	6.5	21.5							

TABLE 1 (continued)

Station no.	Time	Tide	Description	Salinity (ppt)	°C	Standard plate count per ml	Mpn coliform per 100 ml	Mpn fecal coliform per 100 ml	µg-at/l nitrate	µg/l nitrate	µg-at/l phosphate	µg/l phosphate
21	13-VI-68		shore, surface	8.6					23.20	324.86	0.83	25.67
			bottom, 1 m depth	21.6					1.26	17.64	0.49	15.07
	1500 28-X-68	+1.0 falling	shore, surface	8.0	22.0							
			10 m out, surface	22.0	26.0							
			10 m out, 1 m depth	32.0	28.0							
			20 m out, surface	28.0	26.5							
	0715 29-X-68	+1.1 rising	shore, surface	23.0	24.0	20	Negative	Negative				
22	0900 18-X-68	+0.5 ebb	shore, surface	4.0	19.5							
			2 m out, surface	14.0	23.0							
			shore, 5 m south	32.5	26.5							
	1000 28-X-68	+2.1 flood	shore, surface	32.5	27.0							
	0700 29-X-68	+1.1 rising	shore, surface	19.5	22.5	70	240	6				
23	0630 29-X-68	+1.0 rising	shore, surface	28.0	24.0	110	240	6				
			10 m out, 1/4 m depth	28.5	26.0							
24	0650	+1.0 falling	shore, surface	24.0								
			shore, 5 m north	32.0								
			shore, 5 m south	33.0								

TABLE 1 (continued)

Station no.	Time	Tide	Description	Salinity (ppt)	°C	Standard plate count per ml	Mpn coliform per 100 ml	Mpn fecal coliform per 100 ml	μg-at/l nitrate	μg/l nitrate	μg-at/l phosphate	μg/l phosphate
25	1300 28-X-68	+1.7 falling	intertidal pool	5.0								
			surf	34.5								
	0600 29-X-68	+1.0 rising	intertidal pool	23.0	23.0	780	23	Negative				
26	0610 20-X-68	+1.0 falling	surface, shore	10.0								
			shore, 30 m north	34.0								
			shore, 10 m south	24.0								
	1000 26-X-68	+2.0 falling	shore, surface	28.0	21.0							
			20 m out	33.0	27.5							
	1845 29-X-68	+0.2 ebb	shore, surface	3.0	20.5							
			30 m out, 1/2 m depth	22.5	25.5							
27	0610 20-X-68	+1.0 falling	shore, surface	10.0								
			shore, 15 m north	30.0								
	1000 26-X-68	+2.0 falling	shore, surface	32.0	27.0							
28	1100 29-X-68	+2.0 flood	mean reading, bay surface	34.0	28.0							
			mean reading, 1 m depth	34.5	28.0							
29	1100 28-X-68	+1.7 falling	shore, surface	30.0	27.0							
			50 m out, surface	33.0	28.0							
			100 m out, surface	34.0	28.0							

the tide height. Samples were taken for salinity, temperature, total phosphate content, total nitrate content, dissolved organic matter, coliform count and fecal coliform count. The samples were of both surface and depth, usually taken from a variety of points at the station.

In the case of bacterial sampling, the samples were taken by necessity in a rather high, rising tide. They were at once packed in ice and that morning flown to the Department of Health in Honolulu for analysis.

The phosphate, nitrate, coliform and fecal coliform levels at the brackish-water stations in Kealakekua Bay were compared with the State of Hawaii public health standards regarding water quality (Public Health Regulations, Chapter 37-A). The entire bay meets the standards for "AA Water" save for Kaawaloa Cove, which meets the standard for "A Water," and the area fronting the State dock at Napoopoo, which also meets the standards for "A Water."

AA Water is pristine, characteristic of a wilderness region. A Water is less so, but is regarded as completely suitable for swimming and recreational use. Some values obtained were outside the A Water range, but it was thought with further replications the values would be harmonized. In general, sufficient replicates were not possible to make more than preliminary conclusions about the nature and constituents of the brackish water.

The volume of fresh water percolating into Kealakekua Bay is considerable, and although no region of the shore is completely free of brackish water, seepage was not detected in front of the highest portion of the pali and along the north shore of Palemano Point.

The areas of maximum percolation are four in number and are taken up below in serial order. They are by Umi's Well in Kaawaloa Cove (Sta. 4), the gravelly beach area fronted by private homes facing the State dock (Stas. 12-17), Kahauloa Cove (Sta. 21) and an inlet by T. Ashihara's cottage (Sta. 22). These first three stations are in comparatively sheltered areas where diffusion of the fresh water is slow, and where surface layers several feet in thickness of brackish water are present a majority of the time. The fourth station is exposed and brackish water is scarcely detectable at high tide.

Station 1. Caves off Keawekaheka Point. Refractive turbulence with a glass-bottom view box was noted.

Station 2. Located just west of the end of the jeep road to Kaawaloa Flat. A dry creek bed covered with Batis weed abuts the station. The lens is localized.

Station 3. Cook's Monument landing. The lens is not extensive.

Station 4. Off Umi's Well in Kaawaloa Cove. This is the most abundant station in the northern half of the bay. Brackish water is detectable on the surface of much of Kaawaloa Cove during most tides.

Station 5. Located at the base of a talus slope 300 m south of Sta. 4. The region is not sheltered and brackish water is not detectable at high tide.

Station 6. Located at the north face of a rock pile at the northern end of Napoopoo Beach. Although exposed, the lens is present in moderate tides, and refractive turbulence is evident.

Station 7. The old mullet pond at Napoopoo Beach. The area is swampy and polluted, and it is recommended that it be eliminated or renovated.

Station 8. Surf fronting Sta. 7. The station is exposed and brackish water is only detectable at ebb tide.

<u>Station 9</u>. Rocky inlet just SW of Hikiau Heiau. At low tide the shore is nearly fresh water, and a lens is evident 20 m offshore. Houses front this station, and the bacterial sample taken at the surface, shore showed evidence of contamination.

<u>Station 10</u>. Gravelly inlet just north of the State dock. This station is similar to Sta. 9, except that no houses abut it. Bacterial contamination was not detected.

<u>Station 11</u>. Off the State dock. The depth is approximately 2 m.

<u>Station 12</u>. Sea wall by the State dock. Stas. 12 through 17 are close to one another and, at low tides, a freshwater lens extends over this entire region. However, as this area is less sheltered than Sta. 4 in Kaawaloa Cove, diffusion is much more rapid. No lens at all is detectable at high tide. These six stations are arranged along a gravelly, boulder-strewn, crescent-shaped beach fronted by private homes. The rate of percolation was approximately the same for all six stations.

<u>Station 13</u>. Forty m south of the State dock.

<u>Station 14</u>. Sixty m south of the State dock.

<u>Station 15</u>. Ninety m south of the State dock.

<u>Station 16</u>. One hundred and twenty m south of the State dock.

<u>Station 17</u>. At the end of the passible area walking south from the State dock along the shore.

<u>Station 18</u>. Two m west of a cement boat ramp. The lens is localized.

<u>Station 19</u>. A rocky inlet; similar to Sta. 18.

<u>Station 20</u>. A small, gravelly inlet at Manini Beach. An unused brackish well is nearby. Although the rate of percolation here is considerable, the station is exposed and diffusion is rapid.

<u>Station 21</u>. Kahauloa Cove. A layer of fresh water blankets the entire cove most of the time. This inlet is highly protected.

<u>Station 22</u>. A rocky inlet by T. Ashihara's cottage. The rate of percolation is similar to Sta. 21, and at low tide the freshwater layer is several feet thick and extends several hundred feet into the bay. However, the area is exposed and brackish water is detectable only at the immediate shoreline during high tide.

<u>Station 23</u>. At the canoe landing by Manago's cottage. The lens is never extensive.

<u>Station 24</u>. At the beach fronting the abandoned YMCA camp on the south side of Palemano Point. The freshwater lens is never detectable more than a few yards from shore.

<u>Station 25</u>. A low basalt shelf of rock pools 600 m south of Sta. 21 at the end of a jeep road. Fresh water is visible rising from fissures in the rock, but the rate was never marked, and the region is very exposed. No lens at all is detectable.

<u>Station 26</u>. By the boat landing at the head of Honaunau Bay. Percolation is considerable, and a meter-thick lens extends 20 m out from the shore at ebb tide.

<u>Station 27</u>. South of Sta. 26; a sandy beach fronting public restrooms. The rate of percolation is less than is the case for Sta. 26.

<u>Station 28</u>. Alahaka Bay. Several freshwater "chimneys" were reported by SCUBA divers surveying this area. This is to say, fresh water emerges from fissures in the floor of the bay and rises to the surface as a refractively distorted column.

<u>Station 29</u>. At the point where a pali south of Alahaka Bay enters the sea. Fresh water was detectable 50 m from shore during an ebb tide. No further areas of brackish water were detected south to Loa Point.

Chapter 4

UNDERWATER TOPOGRAPHY

Outline of Chapter

1. <u>Description of study zones established from Keawekaheka Point to Palemano Point</u>. Observations were begun at Keawekaheka Point opposite the cairn (this cairn shows on "Towell photo 278-4" as a white speck) and continued all the way around through the bay to Palemano Point. The line of observations was thus made from one boat run within 100 feet to 250 yards of the shore.

An overlay was prepared as we progressed with notes being made as to the general type of bottom and its changes. The accompanying map (Fig. 8) shows this information with the encircled numbers referring to the following notes. Since these notes were made on but a single boat run and it was a first visit with no knowledge of the general changes to be seen, neither the areas indicated nor the following notes can be considered reliable without their being tested by field-checking. Thus, the following information should be treated as a guide for further field work.

In general, the shore drops off very steeply beyond the ten-fathom line. Sometimes this drop-off is quite precipitous. There seems to be very little coral or anything else on the steep outer slopes. In general, near shore the bottom tends to be covered with an assortment of boulders or, very near the lava bluff that forms the shore, sharply angular fragments. As one progresses seaward the boulders are larger, the largest of them tending to be rectilinear and the smaller tending to be rounded. Likewise, as the ten-fathom line is approached from shore the coelenterate coral cover becomes more dense. That is to say, the individuals are thicker and they cover more nearly 100 per cent of the bottom. In general, the recognizable organisms are only coelenterate corals, fishes and sea urchins. The only macroscopic algal material is almost entirely intertidal

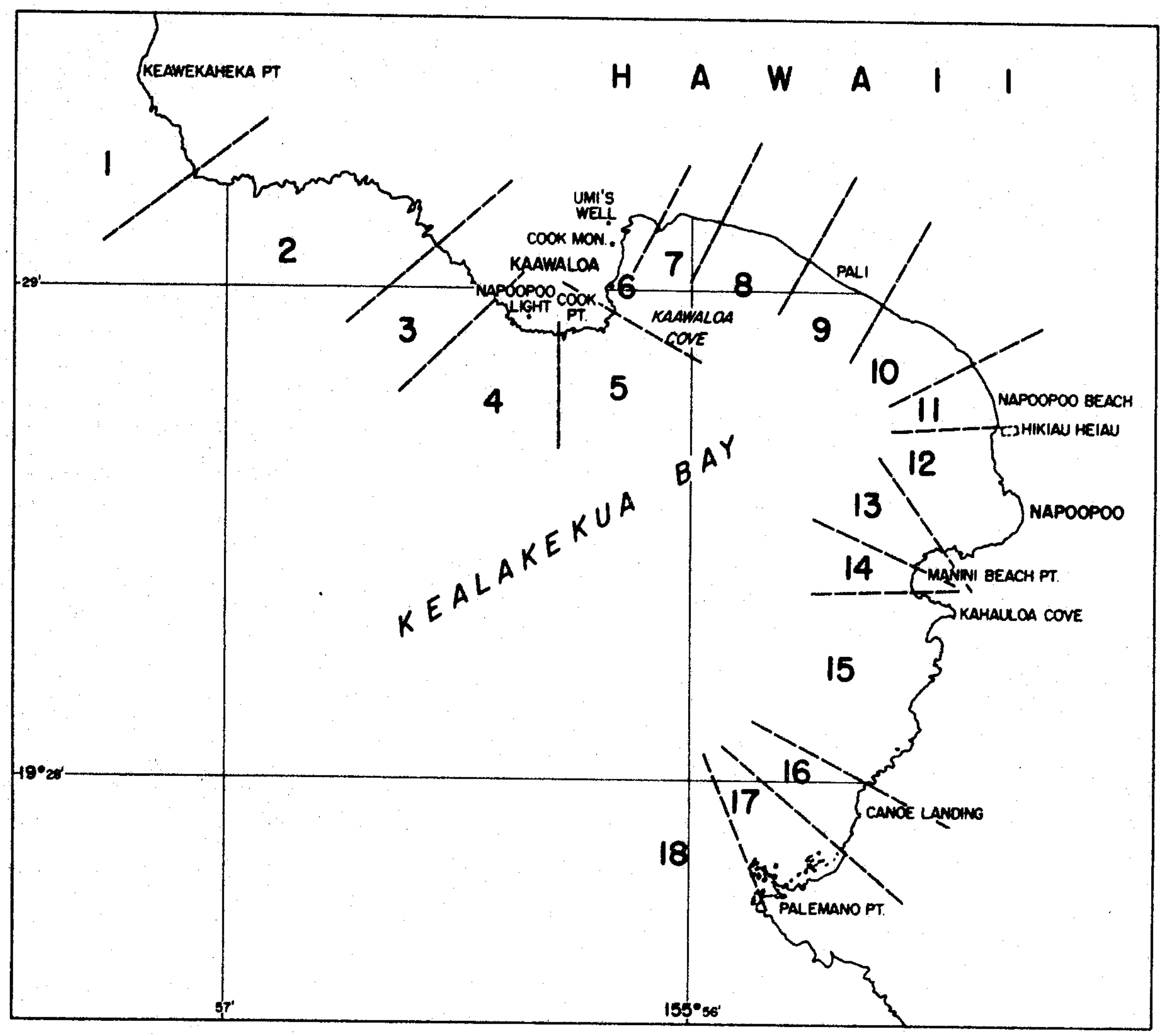


FIGURE 8. Study zone designations.

or on very shallow near-intertidal rocks. Turbinaria ornata was the only macroscopic alga seen in water over two meters deep.

The following notes are descriptive of the different areas numbered on a copy of Coast and Geodetic Survey Chart 4123, with the exception of such drastic shifts as between a coral knoll (a mound covered by several distinctly different genera or species of coelenterates), large coral heads (a single species), or between sand and coral or barren rock. There were no sharp changes between the major areas delineated on this chart and sequentially numbered. The sequential numbers given to the paragraphs below refer to the same encircled numbers on the areas charted, and are placed on the chart at the approximate place of observation. The observations recorded in the numbered paragraphs generally characterize the region set off on the chart by long dashed lines but, of course, were interpreted from the observations made along the single course which the boat took.

1) Huge boulders on the tops of which were many small Pocillopora meandrina heads and discs of some prostrate coral. No algae.

2) Outward near the ten-fathom line there was a 100 per cent Porites cover with a lot of finger coral interspersed with the massive types. Inshore there were a few sand patches. Offshore beyond the ten-fathom line there was no coral visible.

3) Within 100 feet of shore the boulders forming the bottom were often about five feet in diameter, quite well rounded, and had on them very many small Pocillopora-type coral heads.

4) On Napoopoo Light the boulders were very large, and their surfaces were generally barren with very little coral growing on them. (See Jones, 1967, one rife with Ctenochaetus strigosus.)

5) Moving from Cook Point and the Napoopoo Light toward Cook's Monument, the bottom became covered 100 per cent by *Porites* and finger corals. As area 6 was approached at a distance of 50 to 100 feet from shore, many of the finger corals were broken and lying on their sides without having been displaced much from where they must have grown.

6) In much of area 6, 50 to 100 per cent of the finger corals had been broken, and often there was a certain amount of displacement. Sometimes the corals were destroyed in a relatively narrow line, perhaps damaged by the anchoring of vessels. Water so deep the bottom cannot be seen comes very close to shore here. There was a lot of detritus in the water which seemed to be of irregular form and size, as though from the disintegration of jellyfishes or perhaps an aggregation of ecdysed crustacean exoskeletons. Except for this one instance, the water throughout the Kealakekua Bay area was exceptionally clear.

7) In moving from 6 toward 7, the broken finger coral decreased with an increasingly larger percentage of the damage seemingly that which we feel may have been caused by the anchoring of vessels. Toward area 8 appeared the most intensive coral head development seen. However, here and there three-to-five-meter areas were seen where one large coral had died, and near such areas slate pencil urchins (probably *Heterocentrotus mammillatus*) were more abundant.

8) Perhaps this area is best characterized as one covered over 90 per cent by very large (3 to 4 meter) *Porites* heads, having between them narrow crevices. Here and there were dead *Porites* heads densely covered with slate pencil urchins. In some cases coral head substratum was deeply eroded with sharp-edged concavities, many of which were occupied by pencil urchins. (This relationship of urchins and holes reminds one

very much of similar erosion features seen on the inshore edges of very large reef-edged algal ridges in the Tuamotus.)

9) Near this steepest cliff face area of the bay and continuing on around toward Napoopoo, the bottom is completely covered with sand except for a Porites reef very near shore in a narrow band where the water was perhaps two meters or less deep. As far as could be told, in water any deeper than this, and we circled around to check the point, there was nothing but sand on the bottom. This sand bottom had small circular areas about 2 or 3 inches in diameter on it such as are made by various worms.

10) From the boulder point at the southeast end of the pali area to Hikiau Heiau, the grey sand has major ripple marks parallel to the shore. This major pattern is covered with a reticulate, irregular, finer pattern.

11) Beginning at the northern end of the beach and increasing southward, here and there coral mounds appeared on the sand flat until opposite the Heiau they covered about 50 per cent of the bottom. No physical damage was seen to any of these. There was considerable fresh water distinctly colder than the sea, especially just off the Heiau, as sensed by the swimmers being towed behind the boat.

12) The bottom of Napoopoo Bay, itself, is about 100 per cent covered with coelenterate corals. (However, the aerial photographs show a sharp difference in bottom type not noted during this boat run.) The coral bottom cover consists of three to five foot Porites heads with some finger coral between, and as one progresses seaward Pocillopora heads appear.

13) The north shore of this point, Manini Beach Point, is very shallow and as one progresses further westward the *Pocillopora* heads increase until they may cover as much as 25 per cent of the surface. On the shallowest of the volcanic rock surfaces along with the *Pocillopora* there are many dense cone-like *Turbinaria* thalli. This situation was seen off almost each of the ridges of rock running into the sea between Manini Beach Point and Palemano Point.

14) The situation in area 13 concerning *Turbinaria* is more strongly emphasized to the west of Manini Beach Point where the igneous rock knobs of the seaward extensions of each point have unusual amounts of *Turbinaria* on them, but are rather barren otherwise or are sometimes covered with an abundance of quite small coral heads.

15) With the exception of the igneous knob situation described under paragraph 14, above, most of this area is about 95 per cent covered by *Porites* with 5 per cent sand patches at the north end.

16) As the area off the canoe landing is approached, the percentage of sand cover reaches about 50 per cent.

17) Running westward along the shore of Palemano Point the bottom is largely barren rock with a little sprinkling of sand over it but, in some places, it is covered about 50 per cent with *Porites* heads. There were some large, deep (5 to 10 meter deep), barren-bottomed crevices. Some of these had rubble against one edge or another. Since they were rather devoid of sand, it can be assumed that they were channels leading downward toward deep water rather than being mere holes.

18) West of the tip of Palemano Point the bottom is covered with huge boulders, *i.e.*, boulders over four meters in length. There was very little visible growth on them.

It was here that we were passed by a strung-out school of perhaps eighty porpoises, some pictures of which were shot.

Summary Notes

Fresh water was sensed by the swimmers in the water as a sharply lower temperature, and could be sensed otherwise by the refractive turbulence under the glass-bottom box, *e.g.*, off the caves near Keawekaheka Point, conspicuously in Kaawaloa Cove and especially along its inner shores, off the rock pile at the north end of Napoopoo beach and just off the Hikiau Heiau.

Sand dominated all of areas 9, 10 and 11. In general, the sand was grey, darkly so in area 7, and from its association with rubble from the cliff above in the pali area one assumes the color to be that of the rock from which it was derived. Beginning in area 13 it was noticed that the sand was lighter in color, but only in perhaps area 16 did it become buff or the light colors indicative of the coral sand on the north shore of Palemano Point.

In areas 5, 6 and 7 it would appear that the great amount of coral that is broken off without being displaced may have been broken off by people kicking it with their feet or dropping objects directly on it from above and not dragging them as an anchor might be dragged. This does not deny the possibility that much of this damage is from anchors which were not dragged.

2. Transects perpendicular to the shore run from Cook Point to Palemano Point. Seventeen areas (Fig. 9) were selected as sites for transects perpendicular from the shore on the basis of ease of relocation and to provide a representative sampling of the various biota in the bay.

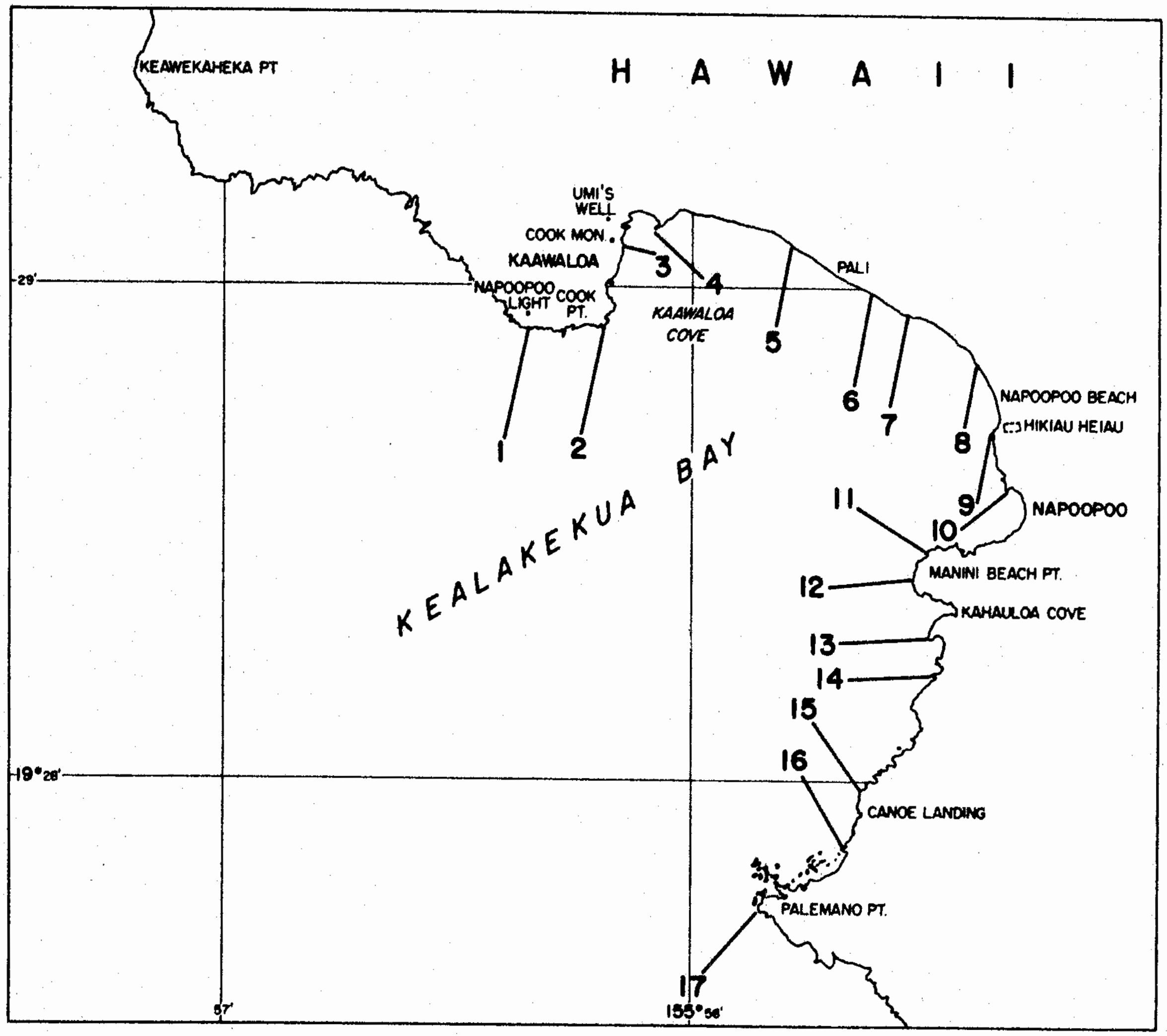


FIGURE 9. Transects by view box run perpendicular to shore.

Each transect was defined verbally and with a compass, and was then re-located during the afternoon sampling effort, during which time each was photographed. Two sets of photographs were taken——one set close to the transect origin and a second more precise set was taken from the terminal point of each visual transect line.

There were 17 visual perpendicular transects run (Fig. 9). During each transect a 17-foot skiff was backed into the landmark as close as surf permitted, and the boat moved as slowly forward as the 10 hp engine would permit. The visual grid sampler (Fig. 11) was placed in the water, the depth and grid used were recorded along with the per cent coverage of each species in the original field of view. The sampler was then lifted, immediately replaced, and the recording procedure was repeated. This process was completed along a compass heading until the bottom could no longer be seen.

Transect 1. Perpendicular to coast, off Napoopoo Light running due south. Sample 1: depth is 50 ft, moving out from the lighthouse, large volcanic rock boulders, covered by about 20% castle *Porites*, scattered *Pocillopora meandrina* heads, the rest volcanic rock. Sample 2: depth is 40 m, 30% *Pocillopora meandrina* heads, volcanic rock rubble, approximately six *Echinothrix* per view, about 30% castle *Porites*. Now about 75 yds offshore. Sample 3: about 50% castle *Porites*, an average of one *Echinothrix* per view, about 10% *Pocillopora*, the rest volcanic rock. Depth 60 feet. Sample 4: depth about 70 ft, 100% finger *Porites*, moving on out, 100% finger *Porites*, one or two castle *Porites* heads, bottom now out of sight, last sighting was 100% *Porites* at depth probably 100 feet.

Transect 2. Compass running on a south setting. Sample 1: depth 50 ft, four *Echinothrix*, about 60% castle *Porites* and about 40% sand-covered lava. Sample 2: about 90% castle Porites, 10% finger Porites. Sample 3: about 60% finger Porites, 40% castle Porites, depth 65 ft. Sample 4: depth is about 80 ft, 90% finger Porites, rest castle Porites. Sample 5 was too deep, it looked like 100% finger Porites.

Transect 3. Landing at Cook's Monument, 8° from mag. north. Sample 1: depth 6 ft, two Heterocentrotus, one Echinothrix, about 40% finger Porites and 60% castle Porites. Sample 2: depth 6 ft, two Heterocentrotus, 20% living castle Porites, 80% dead castle Porites. Sample 3: depth 15 ft, 30% finger coral, 10% castle Porites and the rest dead material. Sample 4: steep drop-off to about 70 or 80 ft, broken finger Porites, dead all along the edge, finger Porites 100%. Sample 5: 100% finger Porites, about 100 ft.

Transect 4. On the northeast side of Cook's Monument. Sample 1: first depth about seven ft, dead Pocillopora with Echinothrix about 5 per view. Sample 2: depth about 30 ft, 100% finger Porites. Sample 3: about 90% castle Porites, 50 ft deep, 10% finger Porites. Sample 4: depth 60 ft, about 70% finger Porites, 30% castle Porites. Sample 5: 100% finger Porites, depth 90 ft. Sample 6: 100 ft, looks like 100% finger Porites.

Transect 5. Off of fallen rock, we are 40-45 ft offshore on a due south heading. Sample 1: depth about 10 ft, lava boulders, no organisms. Sample 2: same type of boulders, depth 15 ft; scattered crusts of castle Porites on boulders. Sample 3: depth 30 ft, one castle Porites per view. Sample 4: depth 40 ft, portion of castle Porites per view, rest volcanic rock. Sample 5: about 30% castle Porites cover, the rest volcanic rock, depth about 60 ft. Sample 6: depth about 45 ft, 30% finger Porites, 60% castle Porites and the rest volcanic rock. Sample 7: depth about

55 ft, 50% finger Porites, 50% castle Porites and 10% rock. Sample 8: 40% finger Porites, about 20% castle Porites and rest volcanic rock. Sample 9: nothing but volcanic rock. Sample 10: nothing but volcanic rock, too deep.

Transect 6. Near the lava tubes, 10 ft from shore. Sample 1: rounded beach-worn volcanic boulders with about 2% castle Porites crusts on them, one Heterocentrotus, depth about 5 ft. Sample 2: less than 1% coverage by castle crusts, depth about 10 ft. Sample 3: about 10% covered by finger Porites, 90% castle Porites. Sample 4: about 20% finger Porites, 80% castle Porites, depth 20 ft. Sample 5: depth 30 ft, one Pocillopora head, about 80% castle Porites, the rest finger Porites and one Echinothrix. Sample 6: 100% castle Porites, depth 50 ft. Sample 7: 10% finger Porites, 90% castle Porites, depth about 60 ft. Sample 8: depth 60 ft, one Pocillopora, 20% finger Porites, the rest castle Porites. Sample 9: depth 80 ft, 100% castle Porites. Sample 10: 50% finger Porites, 50% castle Porites, depth 90 ft. Sample 11: about 70% castle Porites, 30% finger Porites, depth about 95 ft. Sample 12: depth 95-100 ft, about 70% castle Porites and 30% finger Porites. The end is about 100 yards offshore.

In deeper portions of Transect 6, finger Porites did not become as dominant as in the other locations. In all perpendicular transects, a 35 mm photograph was taken from the outermost point of the transect line, in addition to earlier pictures of transect locations. These are labeled and included as future reference guides.

Transect 7. The base of a large cliff; transect runs due south. Sample 1: depth about 6 ft, large beach-worn boulders covered by diatoms, in the cracks are Pocillopora and Porites, each cover about 10%. Sample 2: depth 5 ft, 40% castle Porites, the rest volcanic rock. Sample 3:

depth 20 ft, 10% finger Porites, 10% rock and the rest castle Porites. Sample 4: 100% dark sand, depth was about 35 ft. Sample 5: 50% finger Porites, depth about 45 ft. Sample 6: 80% sand, 10% finger Porites and 10% castle Porites, just small growths, depth about 50 ft. Sample 7: 90% finger Porites, 10% castle Porites, depth about 40 ft. Sample 8: depth about 40 ft, 100% finger Porites, not much depth change here. Sample 9: 100% castle Porites, depth about 40 ft. Sample 10: 50% castle Porites, 50% finger Porites, three Echinothrix per view, depth 60 ft. Sample 11: 50% finger Porites and 50% castle Porites, depth about 65-70 ft. Sample 12: depth 100 ft, about 60% finger Porites and 40% castle Porites.

Transect 8. Sample 1: about 75 ft offshore, 6 ft deep, 100% sand. Sample 2: 100% sand, depth 6 ft. Sample 3: 10 ft deep, 100% sand. Sample 4: same depth, 100% sand. Sample 5: 15 ft deep, 100% sand. Sample 6: 100% sand, depth about 20 ft. Sample 7: 100% sand, depth about 20 ft. Sample 8: depth about 30-40 ft, 100% sand. Sample 9: 100% sand, depth about 40 ft. 100% sand, difficult to tell depth at the end.

Transect 9. Immediately off Hikiau Heiau. Sample 1: depth 20 ft, boulder with scattered Pocillopora meandrina, covering about 50% view, 50% sand. Sample 2: depth 25 ft, 100% sand. Sample 3: 100% sand, depth 30 ft. Sample 4: Pocillopora 10%, sand 90%, depth 25 ft. Sample 5: 50% Pocillopora, 40% castle Porites, 10% rock. Sample 6: 40% Pocillopora, 50% castle Porites, 10% rock, depth 20 ft. The last two samples were over boulders. Sample 7: 100% sand. Sample 8: 100% sand, depth 20 ft. Sample 9: Pocillopora heads covering about 20%, about 20% castle Porites, the rest part of a boulder. Sample 10: Pocillopora heads 20%, one Echinothrix, about 50% castle Porites, the rest rock, depth about 20 ft. Sample 11: 50% sand, 50% castle Porites, depth about 20 ft. Sample 12:

dead castle *Porites* about 70%, living castle *Porites* about 20% and *Pocillopora* heads about 10%, depth was 25 ft.

Transect 10. Napoopoo Harbor, starting in the harbor. Sample 1: volcanic rock rubble with about 1% cover by *Pocillopora* heads, boulders have diatoms growing on them, depth 6 ft. Sample 2: 100% volcanic rock with heavy diatom growth, depth 8 ft. Sample 3: volcanic rock with diatom growth, depth 10 ft. Sample 4: one *Heterocentrotus*, one *Echinothrix*, 8 ft. deep, 50% castle *Porites*, 50% volcanic rock. Sample 5: depth 6 ft, 50% *Pocillopora*, 50% castle *Porites*. Sample 6: 10 ft deep, 100% castle *Porites*. Sample 7: 10 ft deep, 10% *Pocillopora*, 60% dead castle *Porites*, about 30% living castle *Porites*. Sample 8: 10 ft deep, four *Echinothrix* per view, one *Pocillopora*, 10% living castle *Porites*, the rest dead castle *Porites*. Sample 9: 20 ft deep, 100% sand. Sample 10: volcanic rock with 1% *Pocillopora*, the rest sand, depth 25 ft. Sample 11: depth 30 ft, 100% sand. Sample 12: same as last, 100% sand, about 25 ft depth.

Transect 11. South of the first rocky promontory that sticks above the water approaching the harbor. Sample 1: depth 10 ft, 10% *Pocillopora*, 50% castle *Porites*, the rest rock 40%. Sample 2: three *Turbinaria ornata*, 90% dead castle *Porites* and about 10% living castle *Porites*. Sample 3: 100% dead castle, three *Turbinaria*, melobesioid-covered dead castle *Porites*. Sample 4: depth 30 ft, 20% *Pocillopora*, 80% castle *Porites*. Sample 5: 90% castle *Porites*, 10% *Pocillopora*, depth 35 ft. Sample 6: depth 35 ft, 100% castle *Porites*. Sample 7: depth 30 ft, 10% *Pocillopora*, 90% castle *Porites*. Sample 8: depth 20 ft, about 70% castle *Porites*, 30% rock. Sample 9: 50% rock, 50% castle *Porites*. Sample 10: 20% rock, 80% *Porites*, depth about 40 ft. Sample 11: depth 40 ft, 50% finger *Porites*, 50% castle *Porites*. Sample 12: depth about 45 ft, about 50% finger

Porites, 50% castle Porites. Sample 13: depth about 50 ft, 90% finger Porites and 10% castle Porites. Sample 14: 10% sand, 50% finger Porites, 40% castle Porites, depth about 50 ft.

Transect 12. About 50 ft off the beach with Sargassum on the intertidal rock. Sample 1: depth 20 ft, 100% castle Porites. Sample 2: depth 20 ft, 90% castle Porites, 10% sand. Sample 3: about 10% finger Porites, 90% castle Porites, depth 30 ft. Sample 4: depth 30 ft, about 70% castle Porites, 30% dead castle Porites. Sample 5: 50% volcanic rock, 50% castle Porites, one head of Pocillopora, depth 50 ft. Sample 6: 50% castle Porites, 10% finger Porites, 50 ft depth, the rest rock. Sample 7: depth 50 ft, about 100% castle Porites. Sample 8: depth 50 ft, 80% castle Porites, 20% finger Porites. Sample 9: depth 60 ft, 50% castle Porites, 50% finger Porites. Sample 10: depth 70 ft, 30% finger Porites, 30% sand, 40% castle Porites. Sample 11: one Echinothrix, about 60% finger Porites, 40% castle Porites. Sample 12: about 60 ft depth, three Echinothrix, about 90% castle Porites and 10% finger Porites. Sample 13: depth about 75 ft, about 50% finger Porites and 50% castle Porites.

Transect 13. A bent rock in front of a small brown house. The church is 26°; about 10 ft from shore. Sample 1: depth about 7 ft, the substrate is volcanic rock covered with melobesioid growth, one dead Pocillopora head has about four Turbinaria ornata thalli on it. Sample 2: volcanic rock, melobesioids covering 30%, and there is about 30% covering by castle Porites; depth is about 10 ft. Sample 3: depth about 15 ft, about 90% castle Porites, the rest is rock. Sample 4: one Echinothrix, about 70% castle Porites and 30% rock. Sample 5: depth 30 ft, 20% finger Porites and 80% castle Porites. Sample 6: 60% castle Porites and 40% finger Porites, depth about 40 ft. Sample 7: depth about 40 ft, 50%

castle *Porites*, 10% finger *Porites* and the rest is rubble. Sample 8: depth 50 ft, 100% castle *Porites*. Sample 9: 60 ft deep, 50% finger and 50% castle.

Transect 14. We are about 20 ft offshore. Sample 1: depth 10 ft, three *Turbinaria* thalli, volcanic rock with diatoms and one dead *Pocillopora* on it. Sample 2: depth 10 ft, one *Turbinaria* thallus, one *Pocillopora* covering 20%, castle *Porites* covering the rest. Sample 3: running parallel with the wall. Sample 4: about 20 ft deep, 10% dead *Pocillopora*, about 10% castle *Porites*, the rest rock and rubble. Sample 5: 10 ft deep, 60% castle *Porites* and 30% *Turbinaria*, about 25 thalli, the rest is rock. Sample 7: depth about 15 ft, 10% *Pocillopora*, 30% castle *Porites*, rest is rock. Sample 8: 20 ft deep, 50% rock, 50% castle *Porites*, two *Echinothrix*. Sample 9: about 15 *Turbinaria ornata* thalli, 50% rock and 50% castle *Porites*. Sample 10: depth 25 ft, one *Echinothrix*, 50% rock about 30 *Turbinaria ornata* thalli, 50% *Pocillopora*. Sample 11: depth 25 ft, one *Echinothrix*, 100% castle *Porites*. Sample 12: 25 ft deep, 100% castle *Porites*. Sample 13: depth 30 ft, about 90% castle *Porites*, 5% finger *Porites*, 5% rock. Sample 14: 50 ft depth, 50% finger *Porites* and 50% castle *Porites*. Sample 15: depth 85 ft, 100% finger *Porites*.

Transect 15. Sample 1: depth 4 ft, one *Pocillopora*, five small, white sea urchins in the rock, rock is covered with sand and diatoms, *Pocillopora* about 20%. Sample 2: *Pocillopora* about 15%, 85% rock. Sample 3: volcanic rock boulders, one portion of dead *Pocillopora*, two *Heterocentrotus*. Sample 4: depth about 5 ft, three *Heterocentrotus*, 50% *Pocillopora*, the rest diatom-covered volcanic rock. Sample 5: 25% dead *Pocillopora* with two *Turbinaria* thalli, 75% castle *Porites*. Sample 6: *Heterocentrotus* three per view, ten *Turbinaria ornata*, 30% castle *Porites*, 70% rock. Sample 7: 100% castle <u>Porites</u>, estimate 50 <u>Turbinaria</u> thalli in the spaces. Sample 8: depth 10 ft, estimate 50 <u>Turbinaria</u> thalli, 80% castle <u>Porites</u>, the rest rock. Sample 9: 70 ft depth, 50% finger <u>Porites</u> and 50% castle <u>Porites</u>. This is the end of the small hut transect just off of the cabin.

<u>Transect 16</u>. At the south end of the beach near Manago's cabin. Sample 1: 5 ft depth, 80% finger <u>Porites</u> and the rest castle <u>Porites</u> with about four <u>Heterocentrotus</u>. Sample 2: depth 10 ft, 10% castle <u>Porites</u> and the rest volcanic rock carved out quite extensively by sea urchins. Sample 3: about 35 ft depth, about 35% finger <u>Porites</u> and 65% castle <u>Porites</u>. Sample 4: depth 100 ft, 50% finger <u>Porites</u>, 50% castle <u>Porites.</u> Sample 5: about 80% finger <u>Porites</u>, 20% castle <u>Porites</u>; 100% finger <u>Porites</u> into depths out of view.

<u>Transect 17</u>. Out from church on point; intertidal <u>Sargassum</u> on the rocks; about 30 yards off the rocky point. Sample 1: ledge 30 ft deep, volcanic rock with spotty coverage, probably 5% castle <u>Porites</u>. Sample 2: depth 4 ft, 50% <u>Pocillopora</u>, 50% diatom-covered volcanic rock. Sample 3: drops to 40 ft, volcanic rock, 2% castle <u>Porites</u>, 93% rock, 5% <u>Pocillopora</u>. Sample 4: large, rounded boulders with spotty crusts of castle <u>Porities</u> on them, 20% cover by crusts, 80% bare volcanic rock. Sample 5: depth 70 ft, 30% castle <u>Porites</u>, 70% rock. Sample 6: looking into about 80 ft of water, about 10% <u>Pocillopora</u>, 10% small crusts of castle <u>Porites</u> here and there and the rest is rock. Sample 7: depth 100 ft, 20% castle <u>Porites</u>, 40% finger <u>Porites</u>, 40% rock.

<u>3. Transects parallel to the shore run from Keawekaheka Point to Palemano Point</u>. There were 29 transects (Fig. 10) run parallel to the

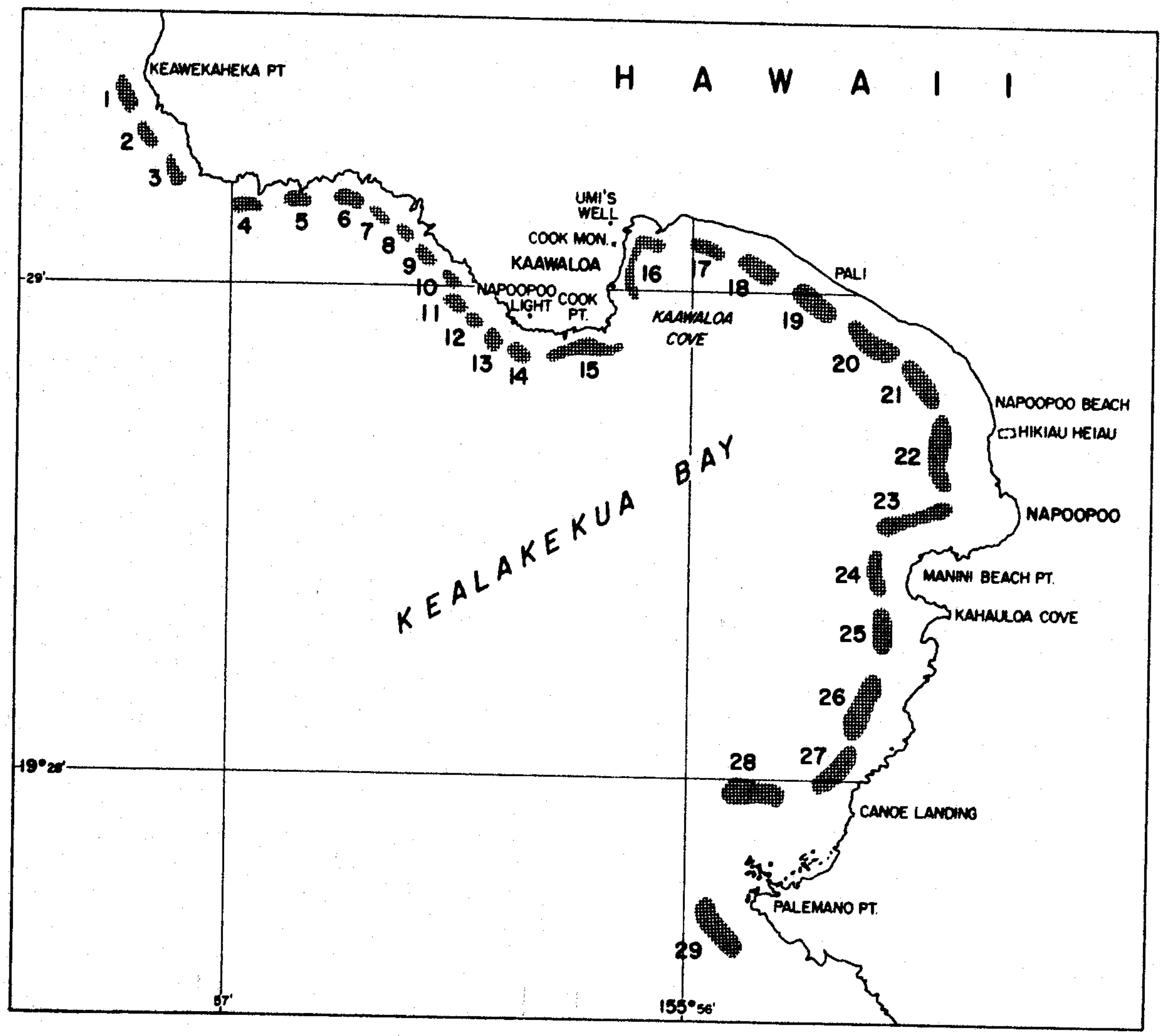


FIGURE 10. Transects by view box run parallel to shore.

shore of Kealakekua Bay, and they varied in length from approximately ten meters to 100 meters. A Midget-tape tape recorder was used to record data.

All transects were made parallel to the shore, and in most cases two starting and terminal landmark fixes were determined, using a hand-held Brunton compass. These were used in conjunction with depth figures in plotting the transect locations on Figure 10. Frequently, estimates of distance from shore were made, as was an attempt to maintain the transect about 50 meters from shore wherever bottom visibility permitted.

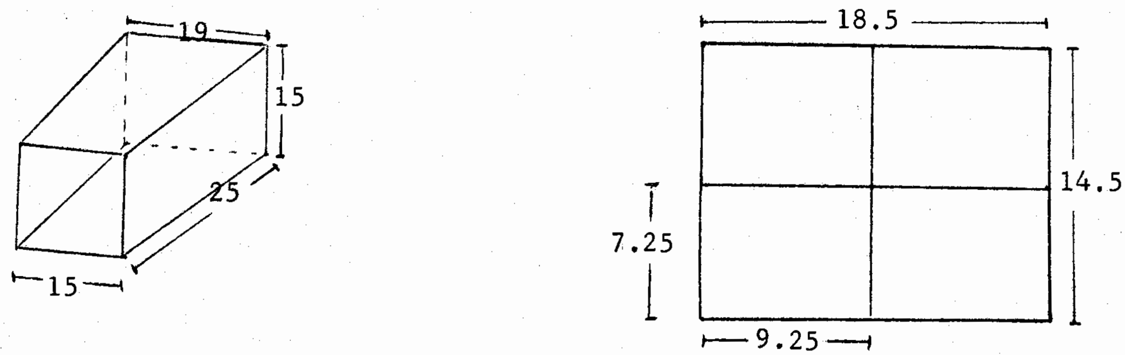
In order to quantify and make observations repeatable, a glass-bottom view box (Fig. 11) was marked off in a grid pattern and calibrated as to field of view per grid. This view box was used in estimating depth and percentage cover by coral formations.

No. 1: Off of Keawekaheka Point, about 30% cover of *Pocillopora*, scattered heads over large rounded igneous rock boulders, about 5% castle *Porites*, and numberous scattered *Turbinaria ornata* thalli in among the *Pocillopora*.

No. 2: Caves just past Keawekaheka Point, finger *Porites* is now becoming slightly more dominant toward Keawekaheka Point, off the 3 caves, 100% cover by corals about 30% *Porites*, finger *Porites* about 40% and *Pocillopora* heads the remainder, scattered rock appearing, coral thinning out again, shelf forms of *Porites*, *Pocillopora* heads scattered, *Turbinaria ornata* thalli.

Directly seaward of Keawekaheka Point *Pocillopora* covering 50% of volcanic rock, the yellow *Porites* covering about 5%, depth is about 20 ft.

Intertidally from the 3 caves area to Keawekaheka Point, we have melobesioids, and just above them at the high water mark, *Ahnfeltia*.



Sample Ranges

Total view:	6 feet deep - 1.5 m^2	
	90 feet deep - 230 m^2	
Quarter view:	6 feet deep - .4 m^2	
	90 feet deep - 70 m^2	

FIGURE 11. View box dimensions (cm).

No. 3: 90 degree angle between rocks, in the open water off the marker at Keawekaheka Point; numerous sand channels, steep dropoff, shelved areas; the depth is ranging from about 8 feet to 30 feet, and the cover is mainly by scattered Pocillopora heads of about 30%; the sand appears a mixture of volcanic rock and calcareous material. Depth varies from 10 to about 30 ft.

No. 4: Approaching the seaward rock mass just to the east of Keawekaheka Point, coverage is about 50% by Pocillopora heads; the heads seem to be much larger in this region; depth varies between 15 and 30 ft; the bottom is 70% covered by Pocillopora.

Depth is 50 ft; almost 100% coverage by coral. Just seaward of the rocks off Keawekaheka Point, about 50 ft deep, cover is almost 80% Pocillopora. They are growing so close to be almost touching each other. Depth is about 50 ft. Just rounding the rocks, Pocillopora heads appear to be somewhat smaller; castle Porites is becoming numerous, 40% Pocillopora and 50% Porites. Past the rocks we have 100% coverage by corals. No volcanic rock is visible and the finger corals dominate, finger Porites cover at least 60% and the Pocillopora heads have thinned out. Castle Porites is 40%, depth 60 ft. At end of run, 29 and 32 degrees magnetic between rocks on point and the pole.

No. 5: The bottom is covered by about 60% castle Porites, and the remainder is finger coral. The depth is 70 to 80 ft, approximately 8° on lighthouse and 29° on pole. The bottom is entirely covered by coral; no sand and no rocks visible; depth is about 60 ft. Bottom covered about 70% by castle Porites, 20% finger Porites and 10% Pocillopora. Depth is about 40 ft. Moving toward the lighthouse at Cook Point, approximately the same 70% cover by castle Porites; enormous colonies of the yellow form are present; the color of these range from yellow to a purple-brown. As one looks deeper the bottom drops off steeply, and along the sides finger Porites dominate.

No. 6: About 50 yards offshore, about 28° to Napoopoo Light. The bottom cover is 100% coral with the castle Porites dominant. It covers about 70% with the remainder 30% finger Porites. Pocillopora heads are scattered sparsely. The depth is 60 ft. We are approximately 30° off some temple ruins.

No. 7: Looking under the natural bridge toward shore, about halfway between Keawekaheka Point and Cook Point, large volcanic boulders form a small beach; these are completely covered by melobesioid algae. The rocks below the cliff at high tide line are covered with partially dead melobesioids and they seem intertidally restricted. Just past the stone arch, going east, the bottom is quite shallow for the same relative distance from shore. The bottom is approximately 60% coral covered. There is no sign of any algae. Pocillopora is dominant, covering 15% of the view, while castle Porites is growing in crusts in about 5% of the view. Moving deeper, several sand pockets appear and Pocillopora is 20% and castle Porites, 15%. No finger corals visible; the substrate is large, rounded volcanic boulders with intermittent sand pockets.

No. 8: 27° and 9° on both points, about 70 yards offshore, depth 50 to 60 ft. The cover is 75% finger and 25% castle Porites; depth 80 to 90 ft; bottom almost entirely covered by finger Porites with scattered Pocillopora heads.

No. 9: Off the point with second set of ruins (ruins number one off kiawe grove); about 80% cover by the castle Porites and 20% cover by finger Porites. There are large, mostly barren volcanic boulders every now and then; depth about 40 ft.

No. 10: About 20 yards offshore, coming to ruins number 2. Depth is 20 ft. The bottom is covered by large, rounded volcanic boulders on which small, yellow Pocillopora colonies are dotted about as are very tiny young colonies of yellow castle Porites; one or two scattered Echinothrix. Echinothrix is becoming more abundant.

No. 11: About 50 yards offshore, 2° off the channel. The depth is 30 to 40 feet; bright-yellow castle Porites, Pocillopora growing on and among them; scattered finger Porites also. About 50% cover by corals; 20% castle Porites and 15% evenly divided between finger Porites and Pocillopora.

No. 12: This is temple number 2, area 3, and we are 4° off the ruins. The bottom is about 20% coral covered; depth about 30 ft. About 10% coverage by Pocillopora and 7 or 8% cover by Porites crusts. No finger Porites present; depth about 30 ft and the substrate is smooth lava with only a few boulders. In the cracks of the lava is a calcareous and volcanic rock mixture of sand.

No. 13: 60 yards offshore of the small light which is about 2°. The bottom is about 70% coral covered, 30% volcanic rock and boulders. The coral coverage is about 50% castle Porites, 10% Pocillopora heads. Off Cook Point are several 20-ft diameter colonies of castle Porites; depth about 35 ft. Due north on Napoopoo Light.

No. 14: Transect parallel to the shore. Depth is about 25 ft. The bottom is covered by rounded boulders; moving parallel to the ruins just to the east of Napoopoo Light. There is an average of one Echinothrix urchin for every five views through the box. The depth varies considerably due to crevices in the rocks; approximately 30% cover by castle Porites in patchy crusts.

There is little Pocillopora and no finger coral. Mostly boulders. Depth is 25 to 30 ft, about 10% cover by Pocillopora. Now 80% of the bottom is covered by castle Porites, 10% by finger Porites and 10% by Pocillopora. The bottom is 100% covered with coral. Now is a patchy sand channel with very little coral, only scattered castle Porites. Now a mound of 40% finger Porites, 50% castle Porites and about 10% Pocillopora. Now off of this mound onto sand and rubble rock. Volcanic rock, 6-inch diameter patchy colonies of castle Porites. Now moving up onto another mound area of about 70% finger and 30% castle Porites. The bottom is 100% covered; depth is 70 to 80 ft.

Deeper, the bottom is covered by 100% finger Porites, commonly dominant on the deeper slopes below about 60 or 70 feet. The finishing angle is 32° on the ruins and 30° on the light; about 30 yards off a small point.

No. 15: 31° to ruins on the point, due north to the point. Moving around the point, large volcanic boulders at 30 ft depth. Three or four Echinothrix in any one view; no other sea urchins; melobesioid algae encrusting some of the boulders. Large Porites castles about 10 ft in diameter are quite numerous. Now 100% cover by coral; 50% finger Porites and 50% castle Porites; no Pocillopora around this point yet. Now about 70% castle and 30% finger Porites. More Echinothrix, some bare rock, some dead castle Porites. Under the castles are numerous Echinothrix. Now 100% cover by about 50% finger and 50% castle Porites. Now we have dead castle colonies in the center and living on the outer margins. Several were seen. Now moving into 100% cover by finger Porites; here and there are scattered castle Porites. Castle Porites more numerous, 100% cover by coral, about 50% finger and 50% castle Porites. Now 100% finger Porites;

shallow depths are almost 100% covered by castle Porites; between is a changing picture of the two. Dead finger Porites is intermittent. Now 80% cover by Pocillopora.

No. 16: Zone 5, 32° on Cook's Monument and 24° on the point seaward of the monument; about 25 yards offshore, depth is 20 ft. The finger corals are broken and dead; these corals are all strewn on their sides. Castle coral is dead with only patches of living material. Scattered Heterocentrotus in among the coral, with several logs, steel bars and so forth left in the water. A rubble of rock is present off a ledge of dead coral. Heterocentrotus and Echinothrix are quite abundant in the cracks around the dead coral. Onto a ledge 30 to 40 meters from the monument is living castle Porites. Just off Cook's Monument the coral is all dead, but does not appear as broken up.

Now is an area of broken coral; deeper, many parts broken away from the large colonial masses lie on their sides in the crevices. The coral is mostly dead; the finger variety broken up the most. Moving to zone 7; still dead corals. Castle Porites and finger Porites present, but the dead is mostly finger. Associated with the dead coral are Echinothrix and Heterocentrotus; the latter is more abundant; some sand pockets present. In among the broken and dead coral are living fingers coming up. The bottom is at least 90% covered with coral.

Castle Porites is dominant at the end of this transect; 23° on the monument.

No. 17: 6° to the fallen rock and 27° to Cook's Monument. Visibility is quite blurred by fresh water. We are in an area of 100% sand; almost entirely volcanic except in wave-cuts there are calcareous particles. Spotty cover by castle Porites. Now about 50% finger Porites cover, 40%

black sand and 10% castle *Porites*; abundant *Heterocentrotus mammillatus* in the finger *Porites*; channel of black sand; then a mixture of 80% finger and 20% castle *Porites*. *Echinothrix* does not appear present here; ridges one after another of castle *Porites* mounds with finger *Porites* along its margin; between are black sand channels; depth 30 ft. 26° on Cook's Monument and due north on bottom end of fallen rock.

No. 18: Directly out from the fallen rock. Depth is 40 ft; mostly black sand with basalt ridges and boulders. Some cover by finger and castle *Porites*, the latter is dominant. End is 50 yards off the bottom end of the beach in front of the fallen rock.

No. 19: 27° on Cook's Monument and 9° on the base of the heiau. Depth is 20 ft; at least 10 *Heterocentrotus mammillatus* per view; crossing areas of dead reef with large *Porites* mounds. Almost every hole has a *Heterocentrotus* and numerous others are scattered in the open; 15 to 20 per view; no fish or finger *Porites* are present; rarely a *Pocillopora* head is present in the large castle *Porites* colonies. The bottom is literally covered with *Heterocentrotus*.

No. 20: 20° on Cook's Monument, 9° on the base of the heiau. The depth and substrate and the amount of urchins are just about the same as cited going into this zone. There are a lot of dark sand channels here. Now 60% cover by finger *Porites*, 10% cover by castle *Porites* and the rest is black sand with scattered lava rubble. Now we are looking down at 100% lava rubble. Now 95% lava rubble, 5% small scattered castle *Porites* colonies. Now 10% finger *Porites*. Now 100% sand which is almost entirely volcanic rock sand and slightly greyish due to calcareous materials; still 100% sand. 27° on the monument and 9 to 10° on the base of the heiau. The area is turbid due to sand; the water is very milky and turbid.

No. 21: Off a pile of large lava boulders piled against the shore. Still 100% sand. Mostly volcanic sand, but there is also quite a bit of calcareous origin. We are due south of the rocks at the end of a ridge running down to the beach.

No. 22: Still 100% sand cover. 23° from the big rock in front of the heiau. Now ridges of volcanic rock covered entirely with various corals; about 60% Pocillopora, 30% castle Porites and the remainder is bare rock; no finger Porites in this area; ridges and then an area of sand, and then another ridge. It appears about 30 to 40 ft between ridges, and the ridges are about 10 to 20 ft across. Depth is 8 ft and now 100% living coral. How it drops to about 25 ft and 100% cover by sand. 9° on the spire and 30° on the monument; approximately off the state pier.

No. 23: Napoopoo Harbor; 3° on the state pier and 10° on the church spire. Depth is 20 ft; bottom 100% covered by coral. In general, the coral cover is various on this transect. Along much of it there is an almost total dominance (80-95%) by castle Porites, depth 20-30 ft. Finger Porites generally has 10% coverage, but 50% is occasionally noted. Only scattered heads of Pocillopora are present.

The area out past the coral about 50 yards offshore appears white on the aerial photographs, and this is probably due to the white sand here. Everything that appears dark closer to shore on the photos is solid living coral; there is no rock visible. Coral covers the rock 100%. The end of this run is about 75 yards offshore. It is 2° on the pier and 29° on Cook's Monument.

No. 24: Cook's Monument is 33°, the lighthouse is 31° and the church spire is 6°. Depth is 20 ft; cover by living Porites castles. As depth increases so does finger Porites. 50% castle at a depth of 30 ft. Now

100% coverage by finger Porites; a rather open growth form, very long-branched with dark areas in between the fingers; highly branched. Now 50% finger, 50% castle Porites, then into sand pockets. 1° on Cook's Monument and 5° on the spire. In 20 ft of water is 80% castle and 20% finger Porites. Now 30 ft with about 80% finger and about 20% castle Porites.

No. 25: 3° on the spire and 31° on Cook's Monument. Depth is 30 ft; scattered white sand patches on smooth volcanic lava; some shallow ledges. This area is quite an irregular underwater cliff-type terrain. Many Heterocentrotus and many Echinothrix are present. Approximately 10% cover by castle Porites.

No. 26: 33° on Cook's Monument and 2° on the church spire; volcanic rock much of which has small channels carved into it by sea urchins; many Heterocentrotus down in the cracks and the bottom cover is about 15% castle Porites except where it drops into deeper water. At a depth of 30 to 35 ft is sand-covered rock with no coral or algae present.

Directly off of Manago's cottage, 200 m from shore, depth 60 to 70 ft, the cover is almost entirely finger Porites.

No. 27: 3° on the spire and 32° on Cook's Monument; about 150 yards off Palemano Point. Depth is about 30 ft. Pocillopora cover about 45%. Pocillopora heads now 10% coverage, and we are getting 10% cover by crusts of castle Porites, and now 5% Pocillopora and the rest is volcanic lava flow. This has quite high ridges that come up within 10 ft of the surface, then drop back to 30 to 40 ft. Down in the 30 ft depth, there is 10% cover by castle Porites. There are only small heads in this area.

No. 28: 33° on Cook's Monument and 4° on the spire; large rounded boulders, worn by heavy surf; about 80% cover by bare rock. Scattered

Pocillopora heads make about 5% cover; another 5% by castle *Porites* and the remainder is sand pockets and rubble fragments. 5° on the spire and 35° on Cook's Monument.

No. 29: Off Palemano Point; 3° on the spire and 33° on Cook's Monument, about 50 yards offshore. Depth is 50 ft. Substrate is volcanic lava with large, scattered lava boulders. Cover is about 40% castle and 15% finger *Porites*. Large *Echinothrix* urchins are quite numerous. There is much less coral on the top of the boulders than on the sides and in the crevices. The per cent cover is about the same on around the point.

4. Kaawaloa Cove underwater transect No. 1. Two underwater transects were made in Kealakekua Bay for this aspect of the study. Both were located in Kaawaloa Cove and were run in a similar manner using the same techniques.

The transect line (a nylon line on a reel, with lead weights and labels at one-meter intervals) was weighted at the bottom with an iron bar that was dropped when the proper depth was reached. The line was used to check the depth gauge used; that is, the Spirotechnique depth gauge was checked aginst a line of known length and found to be accurate with no error at 16 meters depth.

The transect line was then pulled out toward the shore and the reel was deposited on the shore.

Divers went down with recording and photographic equipment to the deepest part of the transect line (in both cases 16 meters) and recorded observations were made as the diver progressed up the transect line into shallower water. The observer used a hand level to determine slope of line and a reeled, metal tape to measure the sizes of coral heads, depressions between heads, and the extent of vegetation.

In cases where vegetation was measured a line-intercept method was used, looking down into the spaces between the fingers of coral.

Transect No. 1 (Fig. 12) is 50 meters in length. It begins at a depth of 16 meters and heads due north, terminating at the prominent rock finger that juts out east of Umi's Well.

Figure 12 indicates the bottom profile with coral types and vegetation types shown. Above the line, plants are noted by letters. Below the line, animal types are noted according to legend.

In general, the slope of the bottom is 20 to 30 degrees, with some pockets and hollows no more than two meters deep and mostly less than that. The lower end of the line is predominately finger coral. The mid-depths are mainly finger coral mixed with crustose and castle _Porites_, while the shallow depths above four meters are characterized by crustose-coralline-covered rock with a few _Pocillopora_ heads.

Sea urchins become more frequent with decreasing depth. _Heterocentrotus_ is more widely distributed, while _Echinothrix_ is localized in depths of six meters or less. Two other species of urchin occur; one with banded spines and one with white spines and a pink body.

The algal growth is distributed between the fingers of the finger coral and in the cracks that run through castle _Porites_. The algal material is localized in mats that occur on the forks of the branched fingers of coral. The lower, dead portions of the finger _Porites_ are covered with melobesioideae and squamariaceae; also _Microdictyon_ and _Amansia_ and others that were not carefully studied.

The algae were dominant in terms of area covered only in the uppermost four meters where they formed a crust of heavily grazed plants. This was mainly one species of melobesioid, perhaps _Porolithon_ _oncodes_.

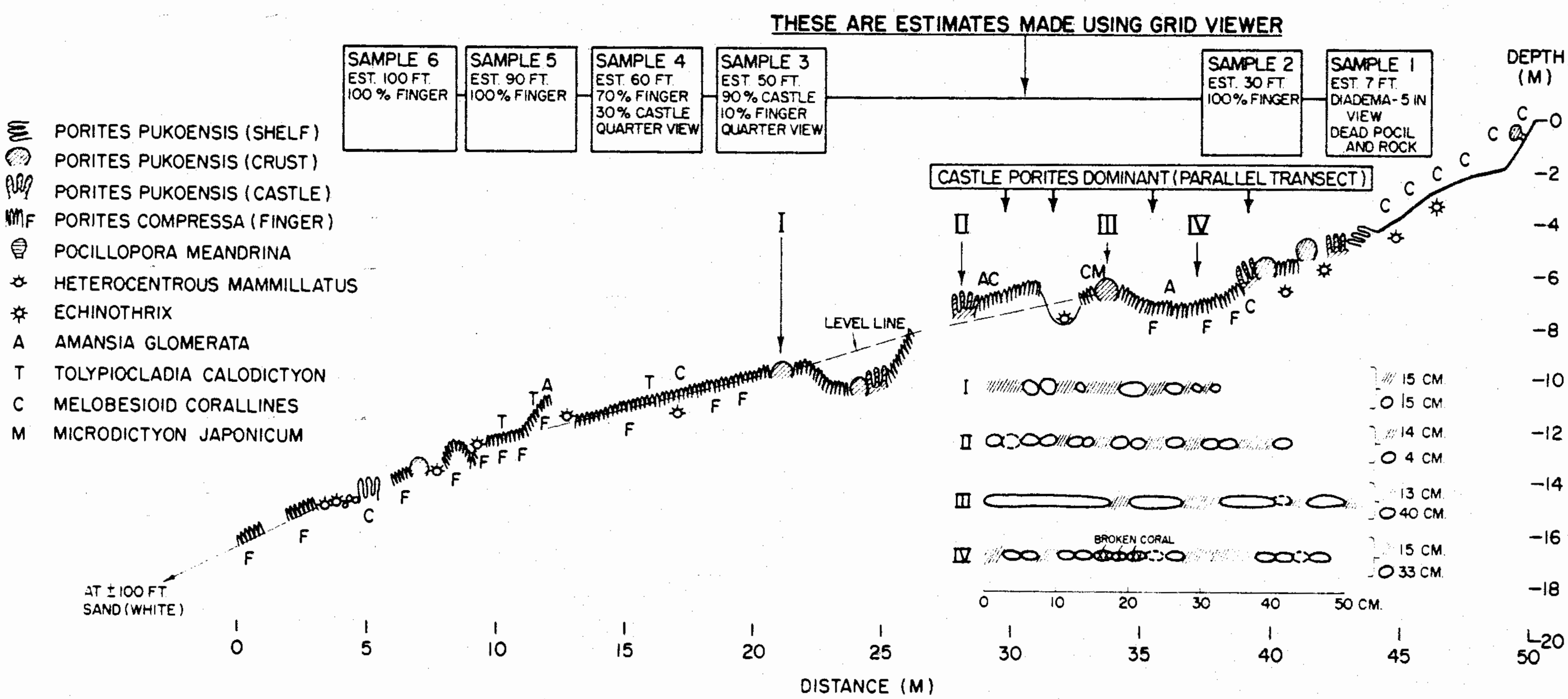


FIGURE 12. Kaawaloa Cove underwater transect No. 1. (DIADEMA in Sample 1 should read ECHINOTHRIX.)

In order to emphasize the importance of the deep water algal vegetation and its probable contribution to the productivity of this area, several detailed transects were run with a hand rule that read in inches. These are listed as sub-transects A, B, C and D. Of these sub-transects, A, B and D were run over finger *Porites*. Sub-transect C was over a crustose *Porites* with cracks in it. In all cases it can be seen that either as much as 50% of the line-intercept was plant material or, particularly where crustose forms were examined, the algal growth was about 25% due to the smaller protected cracks.

It was felt that important algal research could profitably involve quantifying the *Tolypiocladia* mats between the fingers and the sub-distal, reef-forming crustose populations.

The relationship between the detailed sub-tidal transect shown here and the visual transects is indicated by the data in the squares, where depth and the percentage of cover was estimated using a grid viewer. The parallel-to-beach sample area is indicated by notations in a double box.

5. Kaawaloa Cove underwater transect No. 2. Transect No. 2 is 35 meters in length. It begins at a depth of 16 meters and heads due west, terminating at the seaward corner of the cement dock in front of Cook's Monument.

Figure 13 indicates the bottom profile with coral types and vegetation shown.

Above the line, plants are indicated by letters. Below the line, animal types are noted according to the legend.

The coral in this area is limited to the area above about six meters where formations occur above a ledge. Below this depth there are scattered corals, but these are small and did not show up on the transect.

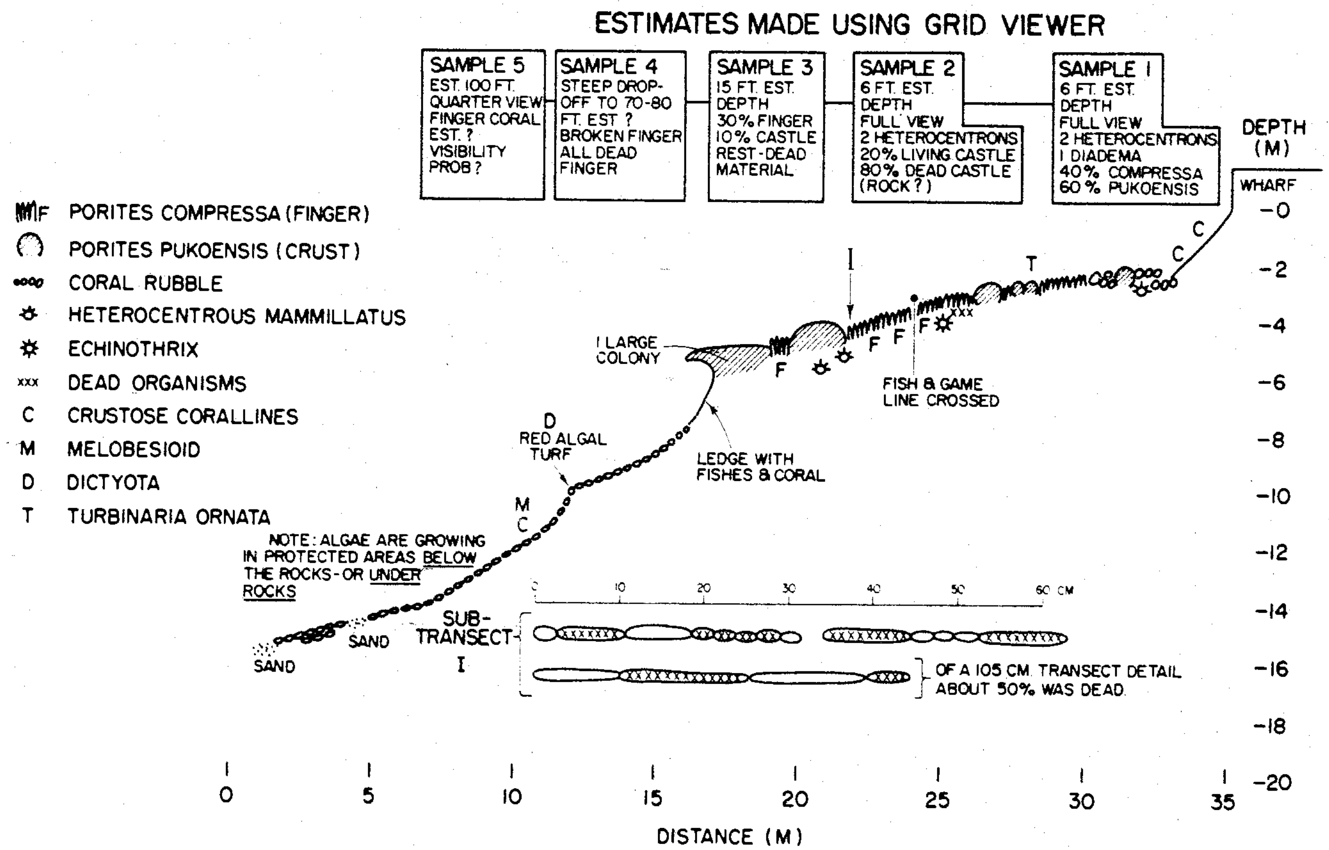


FIGURE 13. Kaawaloa Cove underwater transect No. 2.
(DIADEMA in Sample 1 should read ECHINOTHRIX.)

The rubble and coral fragments below the ledge support a sizable population of algae, particularly down in the cracks between the rocks and even under the rocks. On first examination, however, the area looks very barren and even has a fine whitish silt deposited over it as though the area was somewhat stagnant and free of currents.

Sub-transect A was run just inside the ledge, and it indicates that along a 42-inch sub-transect, about 50% of the coral is dead. Presumably this is due to damage when ships anchor with a bow line in this area. It would seem prudent to put a single or perhaps two anchor buoys in this area to avoid the damage that is obviously produced by individual ships putting down an anchor. Also noted was that the glass-bottom boats have divers who break off pieces of coral.

Urchin distribution is similar to that shown in Figure 13.

In general, it seemed that there was a lot of broken coral in this area, particularly broken finger coral. The rounded heads of castle *Porites* were "worn" or "abraded" in some instances. There is some problem in quantifying this damage in an objective way. This could perhaps be approached later as a distinct problem in itself.

A red-algal mat was not noticed in between the fingers of the coral on this transect.

There is a question here as to whether the rubble below the ledge on this transect is the result of repeated anchoring, or if it is a natural phenomenon. We did not notice finger coral ledges of this sort elsewhere, and at similar depths on the adjacent transect, the bottom was very densely covered with finger coral. Is this long term damage to the coral or is it a natural phenomenon?

6. Description of area from Palemano Point south to Loa Point. The shoreline at a distance of 30 to 80 meters from shore was surveyed by boat with the aid of a glass-bottom view box (Fig. 11) from Palemano Point to Loa Point, south of Honaunau Bay. This survey was not quantitative, but rather its purpose was to check the general pattern and note gross irregularities in the nature of the substrate, flora and fauna; to determine if the bottom conformed in general with the areas more extensively surveyed in Kealakekua Bay.

The south side of Palemano Point at a depth of 10 meters is a smooth volcanic shelf with numerous large boulders; no sand; the crust is 60% to 70% exposed. Pocillopora meandrina and Porites pukoensis (castle Porites) are the corals present; going south, no sand observed at all.

Opposite Keomo Point a sample of brownish-colored seaweed matting, 1/2 cm high, which covered over 50% of the exposed portions of the boulders in this area, was collected at a depth of 10 meters. Similar mattings were abundantly noted on boulders from Palemano Point to Honaunau Bay. Other encrusting seaweeds not scraped off for inspection, but common along this shoreline, consisted of smaller, more isolated patches of blue, green and orange hues.

The sample collected was principally Laurencia sp. It contained a very rich floral aggregation of green, red, brown and blue-green algae, including the genera Herposiphonia, Erythrothrichia, Acrochaetium, Pseudobryopsis (?), Sphacelaria and Calothrix.

Near Kipu Rock the boulders average one meter in diameter and are 80% algae-encrusted, 15% bare and 5% coral-dominated. From this point south to Pehehoni Point the shoreline bluff is spectacular with an abundance of sea-caves and large, natural arches.

South of Kipu Rock and substrate is 100% boulder covered, mostly one-half meter in diameter. This situation lessens, and Moinui Point has an 80% smooth, bare volcanic floor. The boulders are 60% algae encrusted, and up to 30% covered by corals. The only area from Palemano Point to Kanoni Point where sand was observed was on the north face of Kanoni Point where several one-meter patches of gravelly sand appeared.

South of Kanoni Point the bottom is a gently-sloping aggregation of broken rock with 5% coral coverage, over 50% algae encrusted. Occasionally the bare volcanic crust is exposed for periods.

At Pehehoni Point, the substrate at a depth of 10 meters is sand with occasional large boulders and numerous smaller rocks. The cover is 20% Pocillopora and 10% castle Porites. Moving into Honaunau Bay, sand is no longer present and finger Porites (P. compressa) is seen.

Sand patches continue here and there along the north face of Honaunau Bay; finger Porites becomes more abundant, and Pocillopora drops off completely. Enormous colonies of bright-yellow castle Porites appear. Colonies this huge and colorful had not been previously observed south of Palemano Point. Finger Porites grows at the colony fringes. Near the head of the bay, finger Porites is abundant at a depth of four meters. Specimens of this species are rare in Kealakekua Bay at such shallow depths.

The southern face of Honaunau Bay is not traversible by boat. Puuhonua Point drops off sharply with many vertical faces nearly breaking the surface in places. These dramatic vertical faces are unique to the entire region surveyed, and a rich fish population is present. The south side of the point flattens out somewhat, is 80% bare at a depth of 10 meters. Some sand patches appear toward Alahaka Bay, but the bay itself is a flat shelf of lava without sand in evidence. The cover of the bay is 20% Pocillopora, 30% castle Porites and a token amount of finger Porites. From the bay to Loa Point, sand remains absent; castle Porites is the dominant coral with from 5% to 10% cover. The bottom is a smooth basalt floor with occasional large boulders here and there. Some large sea-caves and arches are present at Loa Point.

Chapter 5

PLANKTON

Plankton tows were made at several stations (Fig. 14) in Kealakekua Bay and environs. A 45-cm diameter conical, "Norpac" style plankton net with a pore size of 100 microns was used. It was towed by an outboard motorboat in a figure-eight pattern, at a depth of one meter and speed of approximately 5 m.p.h.

The data obtained (Table 2) indicate the region off Cook's Monument in Kaawaloa Cove (Sta. 12) to be the richest area in Kealakekua Bay in biomass of zooplankton. At this station, 146 mg wet weight zooplankton per cubic meter of sea water was collected, which compares (Sta. 18) with ten mg in the open area 200 meters offshore midway between Kealakekua and Honaunau Bays.

The region off Napoopoo Beach (Sta. 15) was towed on three different dates, and the results indicated considerable variation in the size of the zooplankton population present at these times; ranging from 19 to 129 (mean 77) mg wet weight zooplankton per cubic meter sea water.

It was noted that stomachs of the midwater daytime plankton-feeding fish species, *Cromis ovalis* and *C. verator*, contained little food by comparison with others caught near Oahu, and it was thought this might reflect a paucity of zooplankton.

The zooplankton-station locations (Fig. 14) are described below.

Station 11 is on a line between Manini Beach Point and Napoopoo Light, 150 meters off Cook Point.

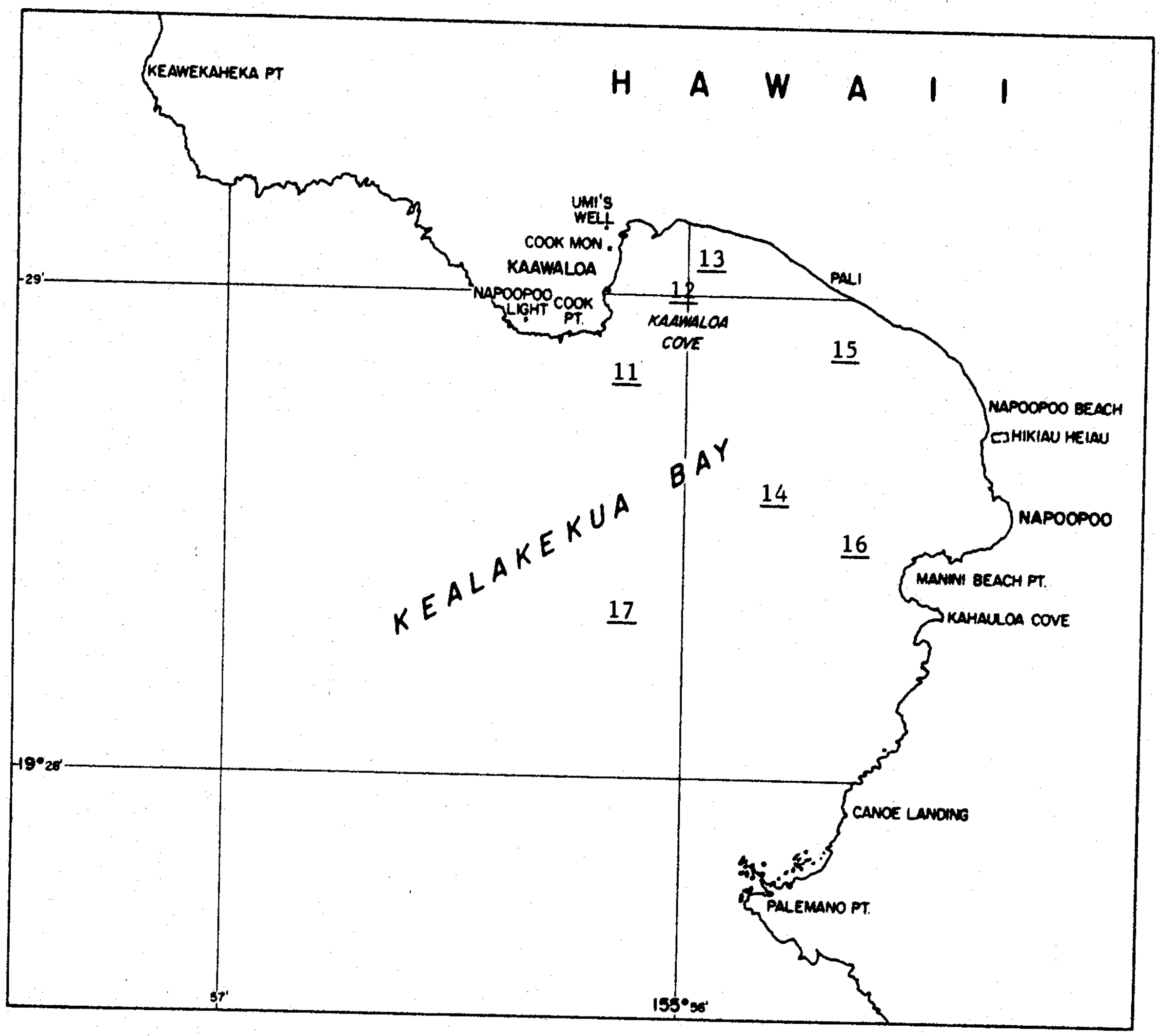


FIGURE 14. Plankton tow stations.

TABLE 2 . The wet weight of zooplankton per cubic meter sea water at various times and locations.

Station number	Time	M^3 sampled	Ml/M^3 settling vol.	Gms wet weight	Mgs wet wt/M^3
11	0900 19-X-68	15.5	0.23	1.12	72.2
12	1400 2-XI-68	39.4	0.48	5.73	145.5
13	1400 19-X-68	19.5	0.33	1.98	101.5
14	1000 19-X-68	16.1	0.22	1.19	74.0
15A	1100 30-X-68	40.1	0.39	5.17	129.0
15B	1100 31-X-68	26.8	0.06	0.50	18.7
15C	1000 2-XI-68	39.0	0.24	3.29	84.4
16	0930 19-X-68	15.7	0.13	0.64	40.9
17	1000 30-X-68	47.2	0.06	0.10	2.1
18	0900 30-X-68	30.1	0.03	0.31	10.3
19	1000 31-X-68	41.4	0.23	3.36	81.2

Station 12 is 80 meters offshore between Cook's Monument and Umi's Well.

Station 13 is located 100 meters off a talus slope at the west end of Kaawaloa Cove. This talus slope is brackish-water station 5.

Station 14 is positioned (in degrees magnetic) 280° to Napoopoo Light, 115° to the church spire and 242° to the tip of Palemano Point.

Station 15 is 50 meters off the center of Napoopoo Beach. Tows were made at this station on three different occasions, and the samples are indicated as 15A, 15B and 15C, respectively.

Station 16 is positioned on a line between Manini Beach Point and Napoopoo Light, 150 meters off Manini Beach Point.

Station 17 is situated on a line between Palemano Point and Napoopoo Light, directly off (due west of) Manini Beach Point.

Station 18 is positioned 322° to Napoopoo Light; 200 meters offshore in front of a fishing shanty at Keomo Point.

Station 19 is as close to the head of Honaunau Bay as towing permits.

Chapter 6

ALGAE

General considerations

There are no conspicuous seaweed beds anywhere in Kealakekua Bay, and the passing observer might conclude that benthic algae are not present. The list of species collected (Table 3) is brief. There was, however, only a single survey directly concerned with algae for, since they are not conspicuous, the present project did not require more. However, it was felt that were more extensive investigations carried out, the majority of Hawaiian species could be found here, but growing only in minimal numbers. It would appear the normal benthic algal role is replaced by zooxanthellae (dinoflagellates) in the extensive coelenterate coral beds.

The only conspicuous alga in Kealakekua Bay at depths over three meters is *Turbinaria ornata*. Generally it grows singly amongst castle coral (*Porites pukoensis*) colonies and in the superficially impoverished southern reaches of the bay. Algal encrustments occur abundantly on boulders and dead coral; and on the bluffs and exposed points of land meeting the sea, a one-meter band of melobesioid algae capped with *Ahnfeltia* is widely apparent. Cowries feed nocturnally in this *Ahnfeltia*.

Algae are discussed whenever applicable in Chapter 4 on underwater topography and in Chapter 3, dealing with brackish areas. It is noted in Chapter 12 that seaweeds favored by turtles, such as *Sargassum*, are generally absent, and this is advanced as a possible reason for the dearth of turtles here.

TABLE 3. Algal species recorded from Kealakekua Bay, June, 1968.

CHLOROPHYTA:

Chaetomorpha sp.
Cladophora sp.
Enteromorpha sp.
Microdictyon japonicum
Ulva fasciata
Valonia aegagropila
Valonia ventricosa

CYANOPHYTA:

Calothrix sp.
Hydrocoleum sp.
Schizothrix calcicola

PHAEOPHYTA:

Dictyota divaricata
Sargassum echinocarpum
Sphacelaria sp.
Turbinaria ornata
Zonaria variegata

RHODOPHYTA:

Acrochaetium sp.
Ahnfeltia concinna
Amansia glomerata
Archaeolithothamnium sp.
Erythrothrichia sp.
Galaxaura apiculata
Gelidium sp.
Grateloupia phuquocensis
Herposiphonia sp.
Jania sp.
Lithophyllum sp.
Lithophyllum sp.
Melobesioid sp.
Peyssonnelia sp.
Porolithon gardineri
Tolypiocladia sp.

Pollution and seaweeds

The lack of beds of seaweed can be taken as related to low fertilizer concentrations in the bay. Whereas in Waikiki seaweeds occur in various quantities, they are hard to find in any quantity in Kealakekua Bay. Yet it would appear there is a very suitable environment for a heavy cover, particularly in the southern reaches of the bay. Of particular note is the near absence of the genus *Ulva*, except near the housing areas and attached as a luxurious mat fringing the glass-bottom float anchored by Cook's Monument in Kaawaloa Cove.

Algal beds are often conspicuous in areas where fresh water and fertilizer are introduced. The principal among these green pollution indicators is the presence of an algal community dominated by the genus *Ulva*, noted above. Large green areas of this sea lettuce, often becoming off-white or yellowish in part, could be expected to develop if a significant amount of fresh water and fertilizer were to percolate into the bay, or even if processed sewage were to be furnished.

The development of a pollution-type marine community in Kealakekua Bay would mean loss of much of the present Hawaiian marine life, and in few other areas is this marine life more readily accessible to the itinerant.

A marine shore area in balance suddenly receiving quantities of fertilizer flushed in with fresh water will alter in adapting to the new conditions. The expected pattern is for a series of near-irreversible changes to occur. The first changes to be seen are in the microscopic algal organisms, those essential to the larval animal stages and utilized (as zooxanthellae) by coral adults. The results are newly dominant species of the short-lived, frequently reproducing kinds. In this case, they will be those relatively insensitive to or stimulated by the addition of fresh water and the fertilizers derived from sewage. In the tropics these are usually members of the Ulvaceae; *Enteromorpha* if a steady supply of fresh water is involved, or *Ulva* if the fresh water is less or periodic and contains increased nitrogenous wastes. Thus, it is that a splash of green from these seaweeds in front of a residence or bathhouse indicates pollution.

An *Ulva* community is usually strangely devoid of animal life or much of any living material other than the seaweed *Ulva* itself. Many explanations have been offered for this, but wide variations in the oxygen content of the water and the production of toxic materials are two which do function to the exclusion of animals.

With the advent of sewage disposal in Kealakekua Bay and such populations as the above appearing, the natural food for the native organisms decreases. Thus, the fish and other animal populations would decrease to the extent they did not consume the new algal population or the pollution material directly.

Vertical zonation

The site concerned is about fifty feet west of the first canoe landing which one comes to in driving from the shore road seaward along the road leading to Palemano Point. The surfaces concerned were vertical, rising from a pool. This pool had arisen apparently by the removal of the half-meter thick dome of a blister in the lava.

The bottom of the pool is of solid igneous rock. At low tide on 4-VI-1968, it was generally covered with one- to ten-inch flattened boulders having on them coralline and Peyssonnelia-like spots or coatings. These were seven inches below the water surface at this time. A photograph was taken of the area above the water line looking shoreward across the pool from a distance of about eleven feet from the far edge which shows in the photo. In this photo the distance from the water to the bottom edge of the barnacles, which show as white spots, is nineteen inches. Ulva ran from four inches below the water line to about eight inches above it. A band of Ahnfeltia concinna (14972*/) up to eleven inches wide,

*/ Such numbers are the numbers on voucher specimens.

extended on above the Ulva to the barnacle levels. Total height of the barnacle zone was about five inches. It was scattered over seaward-facing levels at this same elevation inland for a distance of fifteen or so feet on each vertical sea-facing surface. When these surfaces extended below that level, at least in cracks, scrubby, stubby, small Ahnfeltia was present in them.

Throughout much of the Ulva zone Valonia aegagropila (see 14976) was present, the Ulva being the more dominant on the northward and sun-facing slopes, the Valonia being the more abundant on the slopes shaded in the late afternoon. While not in these pool areas, nearby in the entrances and cracks where the same zonation was present and there was a strong current, a Gelidium appeared below the Ulva. Where constantly or nearly constantly awash on the wave-exposed shores, Colobocentrotus (sea urchin) and corallines extended above Sargassum, though in some places there was a little Ulva below it. In pool entrances there was considerable Ulva with Sargassum just below the Ulva and extended downward irregularly as much as one foot depending on exposure. On more seaward vertical faces, facing seaward and not on the pool and inland-facing otherwise similar steep or vertical surfaces, just above the Sargassum there was sometimes Grateloupia phuquocensis (14974) and various other fine algae (14973, 14976) some of which were collected for identification as was fruiting Ahnfeltia (14972) and under its pendant branches Chaetomorpha (14975).

Chapter 7

CORAL

August 5, 1968. Transect from cove in front of T. Ashihara's cottage. On the afternoon of arrival a skin-diving survey was made from the shoreline at the cottage to a distance approximately 150 meters offshore. The area studied would comprise the region encompassed between the view box transects 13 and 14 (Fig. 9) of the initial investigations. The area immediately adjacent to the cottage is a small rocky cove. This is a protected area, whereas the areas to each side are exposed to the full impact of the surf. The substrate in the cove is composed of large, loose boulders, and temperature differentials suggest considerable fresh water is carried into the cove (no samples were taken for verification). Near the mouth of the cove there are lava boulder ridges that are perpendicular to the shore. These ridges serve as the substrate for heads of *Pocillopora meandrina*, great masses of *Palythoa* sp. (a soft coral), and extensive colonies of the alcyonarian *Sarcothelia edmondsoni*. This biotope is quite characteristic of similar substrate and exposure conditions on both the islands of Hawaii and Maui. The corals in this region are well within the region for fresh water exposure during periods of low tides. They occur below the level of scouring by surf and deposits of sediments. It is evident that some of the *P. meandrina* heads occasionally settle close to shore, but these do not survive for long periods nor do they grow to any significant size if they do survive. The ridges were found to extend to the extreme margin of the survey (150 meters from shore). The depth at this point was 5-10 meters. At this point there occur large sand deposits between the channels of the ridges which have tended to diverge from one another. In the sand pockets there occur occasional lava outcroppings which are found to be colonized principally by the encrusting coral *Porites pukoensis*. These are isolated encrusting masses on the boulders, and do not form large heads that are characteristic of this species. Near the base of each of these masses one may also find two or three other species of madreporarians listed in Table 4.

TABLE 4. Anthozoan fauna of Kealakekua Bay inhabiting the region between Transects 13 and 14.

1. From shore to 150 meters; on lava ridges; 5-10 meters depth

   Pocillopora meandrina
   Zoanthus sp.
   Scarcothelia edmondsoni

2. 150 meters and beyond in sandy surge channels; 10 meters or greater in depth

   Porites pukoensis
   Porites compressa
   Pocillopora meandrina
   Pocillopora ligulata
   Montipora verrucosa
   Pavona varians
   Pavona explanata
   Psammocora stellata
   Leptastrea purpurea

August 6, 1968. Underwater transects at Captain Cook Monument. Observations made by skin-diving perpendicular to the landing at the monument and at three other points 25 meters to each side has made it possible to postulate four faunal zones within the upper 25 meters depth. A fifth zone has been appended from the observations made by SCUBA divers at depths between 25 and 40 meters. These zones may be considered to comprise the region of Kaawaloa Cove, extending between Cook Point and view box transect 4 (Fig. 9).

Zone 1. 0-5 meters depth. Immediately adjacent to the shore and to depths of about 5 meters (the horizontal extent of this and all other zones depends upon the steepness of the slope in the particular region) there is a distinct coral fauna composed of *Porites pukoensis*. Both of these species are found as scattered colonies encrusting masses of rubble in this area. The zone is easily recognized by the presence of conspicuously large heads of *Pocillopora meandrina*. This species is rarely found or completely absent at depths greater than 5 meters. The soft coral *Palythoa* sp., and the alcyonarian *Sarcothelia edmondsoni* are also present in this zone, as in the survey made at the opposite end of the bay. It was noted that immediately in front of Umi's Well great masses of the coral *Pavona explanata* were present. Elsewhere in Hawaii this species only occurs as isolated clumps. In this zone heads approximately 10 meters in circumference and 1-1/2 meters high occur. It is apparently limited in its upward distribution by the tidal level. Near the boundary of this zone with the following one occasional clumps of the solitary coral *Fungia scutaria* were found. These occurred in crevices between the larger coral and algal masses.

Zone 2. 5-10 meters depth. This zone is recognized as the *Porites pukoensis* zone. It begins as sparse colonies on the encrusting coralline algae and lava boulders in Zone 1; but within this region large masses of this coral consolidate much of the rubble. Thirteen other species (6 genera) of corals presented in Table 5 comprise the madreporarian fauna of this zone. In contrast only 7 species (5 genera) were recognized as occupying Zone 1.

Zone 3. 10-15 meters depth. This seems to be a continuation of Zone 2; but there is less diversity in the species composition of the corals. *Porites pukoensis* is the dominant form, and the substrate is more uniformly covered with coral. Near the base of the heads of *P. pukoensis* and in the crevices are sheets of encrusting *Pavona varians* and *Leptastrea purpurea*.

TABLE 5 . Coral species occurring at Kealakekua Bay in Kaawaloa Cove 5-10 meters in depth. (Zone 2)

Species	Frequency
Porites pukoensis	++++
Porites compressa	++
Psammocora stellata	+++
Pavona explanata	++++
Pavona sp.	++
Pavona clava (?)	+
Pavona minuta	++
Pavona varians	+++
Cyphastrea ocellina	+++
Leptastrea purpurea	+++
Montipora verrucosa	++
Montipora sp. cf. *studeri*	+
Montipora colei (or *granulosa*)	+++
Leptoseris hawaiiensis	+++

++++ ubiquitous

+++ common

++ occasional

\+ rare

Zone 4. 15-20 meters depth. An intensive survey of this region was not carried out because of the depth. The horizontal distribution of this region may be very variable. In front of the monument it is extensive, but at Cook Point and Umi's Well it is restricted. It is possible to draw the conclusion that penetration of light and temperature may be important in establishing the limits. The amount of rubble and disturbance by winter surf and currents may also be equally important. The zone is recognized by the abundance and almost universal coverage by the highly branching coral _Porites compressa_. Most of it was found to be dead, but in almost all instances the terminal branches were alive. The base of the colonies is most frequently dead, and this provides substrate for the encrustose forms _Leptoseris hawaiiensis_ and _Pavona varians_. Both of these species are similar in their growth patterns and habits. At the lower end of the depth of this zone _Montipora colei_ (or _granulosa_) may grow around the branches or completely cover colonies of _Porites compressa_.

Zone 5. 25-40 meters depth. Wherever there is a continuing slope (extending to the bottom which ultimately becomes sand and loose rubble) great sheets and plates of _Montipora colei_ (or _granulosa_) occur. This fragile, plate-like coral grows over other materials on the slope, and hence prevents other species from growing outward or upward. It seems more likely that the distribution of this species in the vertical direction is limited by light penetration, temperature and possibly food. Any one of these may serve as an isolating mechanism, or they may act together.

Napoopoo transect parallel to shore. A shallow water transect within the region covered by view box transect 9 (Fig. 9) extending approximately 100 meters from the Heiau to the boat ramp was made. The depth of the water at this area was found to be a maximum of 5-6 meters and approximately 50 meters from shore. This region is similar to the conditions prevailing in front of the cottage (Transect 13 and 14). The lava is eroded such that there are surge channels perpendicular to the shore. Between the walls of adjacent channels fine sand and loose gravel are abundant. Hence the area supports little coral growth in contrast to that found at the opposite end of the bay. Coral is restricted to the sides and upper ridges of the channels.

A brass chain was stretched along the bottom of the transect. At 5-meter intervals the population of corals (1 m^2) on each side of the chain was recorded. This method was found impractical, and ultimately only the record of the presence of a species at a particular point was recorded.

In analyzing the records from this transect one is immediately impressed by the homogeneity of the coral and anthozoan population. It has provided additional evidence that the subjective zonal regions established at Cook Monument also exist at other regions in the bay. Although the presence of sand in this area seemed to preclude the application of zonation to the corals, the presence of boulders or lava ridges provided adequate substrate for colonization throughout the length of the transect. Eight species of coral, soft coral or alcyonarians were found along this transect. The three dominant species (occurring in 33-50% of the sample areas) were Pocillopora meandrina, Porites pukoensis and Montipora verrucosa. Lower frequency of occurrence for Palythoa sp, Sarcothelia edmondsoni, Leptastrea purpurea, Pavona varians and Pocillopora ligulata were also found (10-25%).

Seaward from this transect the bottom topography was found to be a gentle slope for long distances. The bottom is chiefly sand, and occasional large boulders are found to support colonies of corals and soft corals. On one such boulder (100 meters from shore) a large colony of Pocillopora eydouxi (syn. P. modumanensis) was found. This is a species that is rarely found in shallow water. They have branches up to 3 feet in length and are very stout. This solitary specimen has branches approximately 2 feet in length. It is isolated by the surrounding sand at a depth of about 10 meters.

August 7, 1968. Underwater coral survey using transects and quadrats. Employing the procedure from the survey above, a similar technique was followed for more objective assessment of the coral zonation at Cook Point, Umi's Well and the area between view box transect 4 and 5 (Fig. 9). Measurement of depth and distance from shore were possible using this method, whereas previously these were estimated.

The data at Cook Point is summarized in Figure 15 . This is an exposed area and swells and surf are prevalent. The angle of descent is steep. Pocillopora meandrina was found to be represented in 17% of the quadrats and comprised about 14% of the total species recorded. However, it can be seen in Figure 15 that this species is principally restricted to the first 8-10 meters from the shoreline. An occasional head was found to occur within the first 20 meters, but this is thought to be due to unusual substrate conditions. The records of P. pukoensis show that this species overlaps the range of distribution of P. meandrina, but that it is much more extensive in its distribution. It should be noted that the overlap could be accounted for by depth alone.

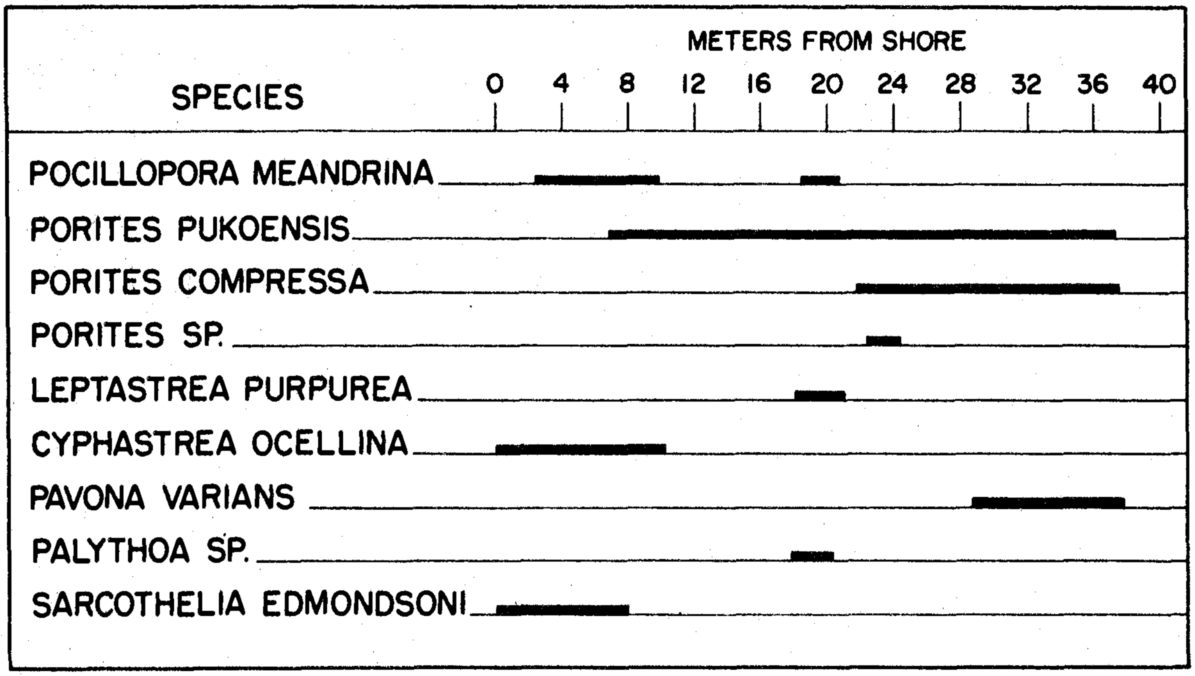


FIGURE 15. Kealakekua Bay underwater coral survey. Transect from shore seaward at Cook Point, August 7, 1968.

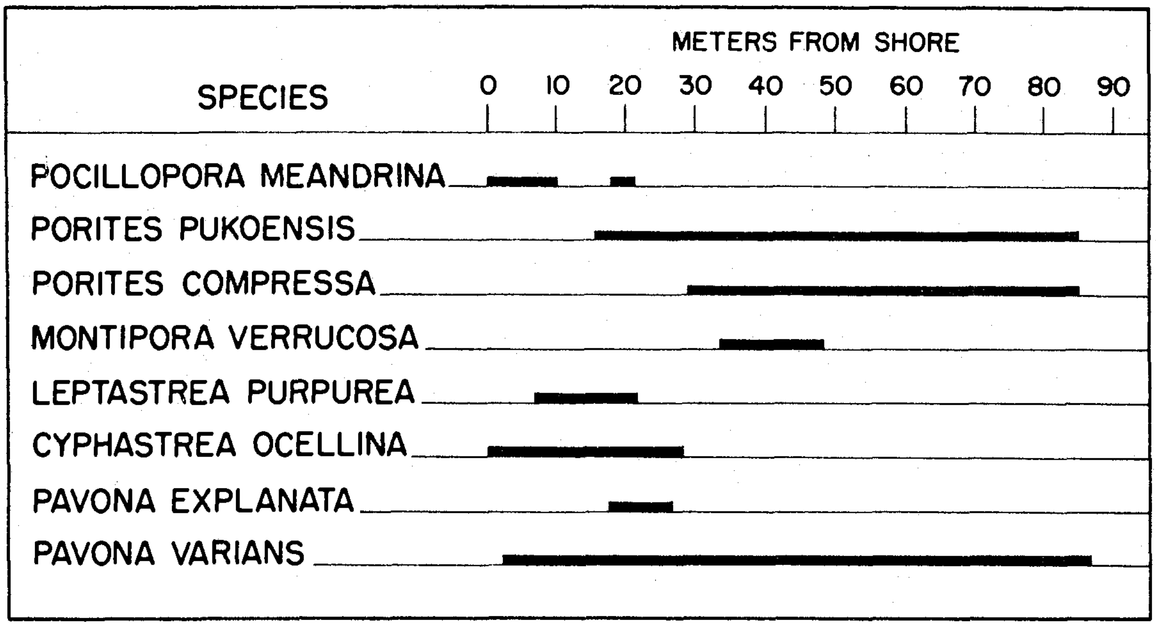


FIGURE 16. Kealakekua Bay underwater coral survey. Transect at Umi's Well, August 7, 1968.

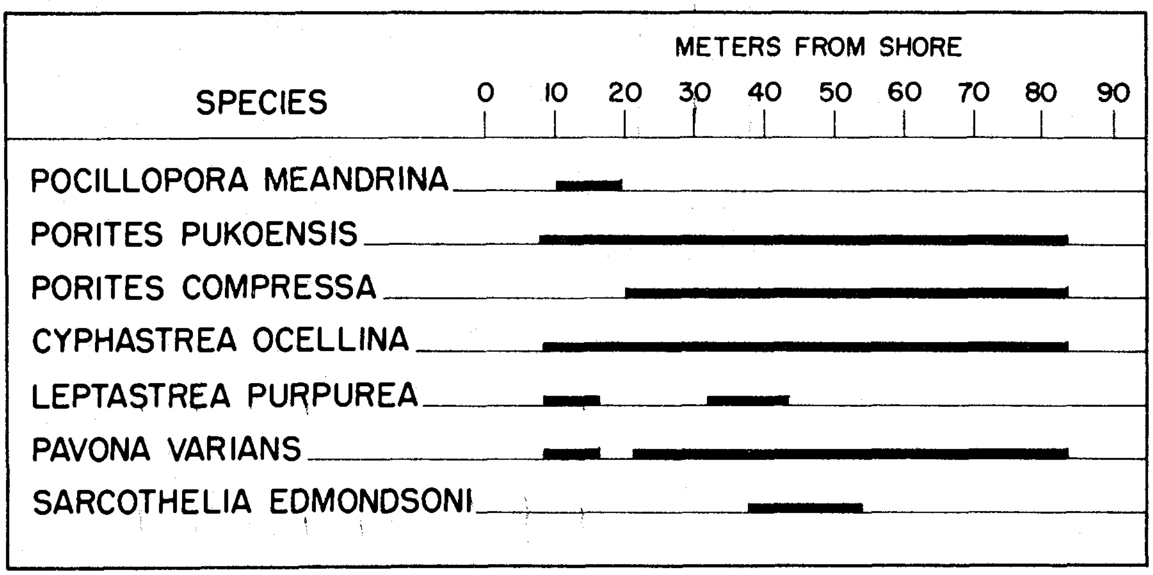


FIGURE 17. Kealakekua Bay underwater coral survey. Between view box transects 4 and 5.

The region occupied by P. meandrina is the upper 2-5 meters; whereas P. pukoensis was not represented in any quadrat samples until the depth was 5 meters or greater. This species comprises 36% of the quadrat records, and about 30% of the total species over the entire range investigated. The congener P. compressa was found to be located at a distance of 20 meters from shore, and then continued throughout the remaining samples. It also appears to be related to depth of the water, because it first appeared in the transect at a depth of 7 meters (this is borne out in the other sampling areas). It comprises 17% of the quadrats for this transect, and 14% of the species composition. These three species, therefore, represent 65-70% of the coral population for this particular region. Six other species are represented in this sample, but only Cyphastrea ocellina and Pavona varians occur with reasonable frequency.

The transects made at Umi's Well and between view box transects 4 and 5 are summarized in Figures 16 and 17. These figures demonstrate that the observations made at Cook Point and the previous evaluation of the zones was indeed valid, the only difference being that Pavona varians is much more common in these two transects than at Cook Point. The information shown in Figure 17 can be somewhat misleading. It tends to indicate a general homogeneous population of corals for a wide range. This is indeed true; but the size and numbers of specimens at any time is less than found in either of the other transects. This can be ascribed to the loose rubble and sand in this area. There is a very wide talus slope formed from the rocks falling from the surrounding cliff. The area is therefore very similar to the conditions found at the boat landing in Napoopoo. This area seems to be less disturbed by surf and swell than at Napoopoo. This may be due to a protection afforded by Cook Point deflecting and damping waves as they enter the cove.

Chapter 8

MARINE MOLLUSCS

Introduction

The marine molluscs of Kealakekua Bay may well be unparalleled in any other similarly circumscribed area in the Hawaiian Islands in a number of important respects. These include species diversity, densities, peculiarities in faunal composition and habitat differences. A total of approximately 170 species were identified from the bay.

Examples of peculiarities in faunal composition would include the snails, *Gibbula marmorea* and *Leptothyra verruca*, which are among the dominant epifaunal elements in tidepools and shallow waters on Kauai and Oahu, but are virtually absent in Kealakekua Bay. Although not considered particularly abundant, tiger cowries (*Cypraea tigris*) and triton's trumpet (*Charonis tritonis*) were collected at depths of 10 feet, whereas they are found at depths of 30 to 40 feet off Kauai and Oahu. Opihi (*Cellana sandwichensis*) and auger shells (*Terebra*) were very abundant, their densities estimated at $68/m^2$ and 30 to $40/m^2$, respectively.

These and other phenomena contribute to making this survey of the marine molluscs of Kealakekua Bay of both general and particular biological interest.

Three general types of habitat are recognized in this account: high shoreline, intertidal cliffs and benches, and subtidal reaches. Each of these is then subdivided into more specific habitat types. Descriptions of the localities, habitats and associated species are given below. Numbers correspond to those of the locality maps (Figs. 8 and 18), and Figs.19 to 25 represent sections through the habitats from some of the base points.

The High Shoreline

SPRAY ZONE. The spray zone, termed also the upper shore or supralittoral or strand, is recognized as the seaward fringe of Kealakekua Bay, and consists of lower reaches of a strand flora of coconut and kiawe trees and the shrub, naupaka (*Scaevola*). From Napoopoo Light to Palemano Point, the substrate is comprised of black pahoehoe (smooth) basalt (Fig. 8 , Zone 1), sand patches (Zone 3) and loose rock and rubble (Zones 7 & 9).

Despite its apparently barren and dry surface, populations of some of the zoologically most interesting, also the most colorful, marine molluscs are found here, including the pulmonates, *Melampus* and *Pedipes*, and the minute prosobranch, *Assiminea*. These molluscs are not uniformly distributed, but rather are found in colonies among loose rocks and rubble. Often their densities exceed $100/m^2$. The snails remain concealed under rubble and rocks and in crevices during the day, but at night and on cloudy days swarm over the rocks apparently feeding on decaying vegetation and fungi.

SPLASH ZONE. The splash zone is defined here as that fringe of the high shoreline wetted by splash or waves approximately once during each 24-hour period, and which is covered by water during extremely high surf or tide conditions. The substrate consists chiefly of a relatively smooth pahoehoe bench from Napoopoo Light to Cook's Monument (Fig. 8 , Zones 1-3), and alternately of rough, pitted aa lava bench

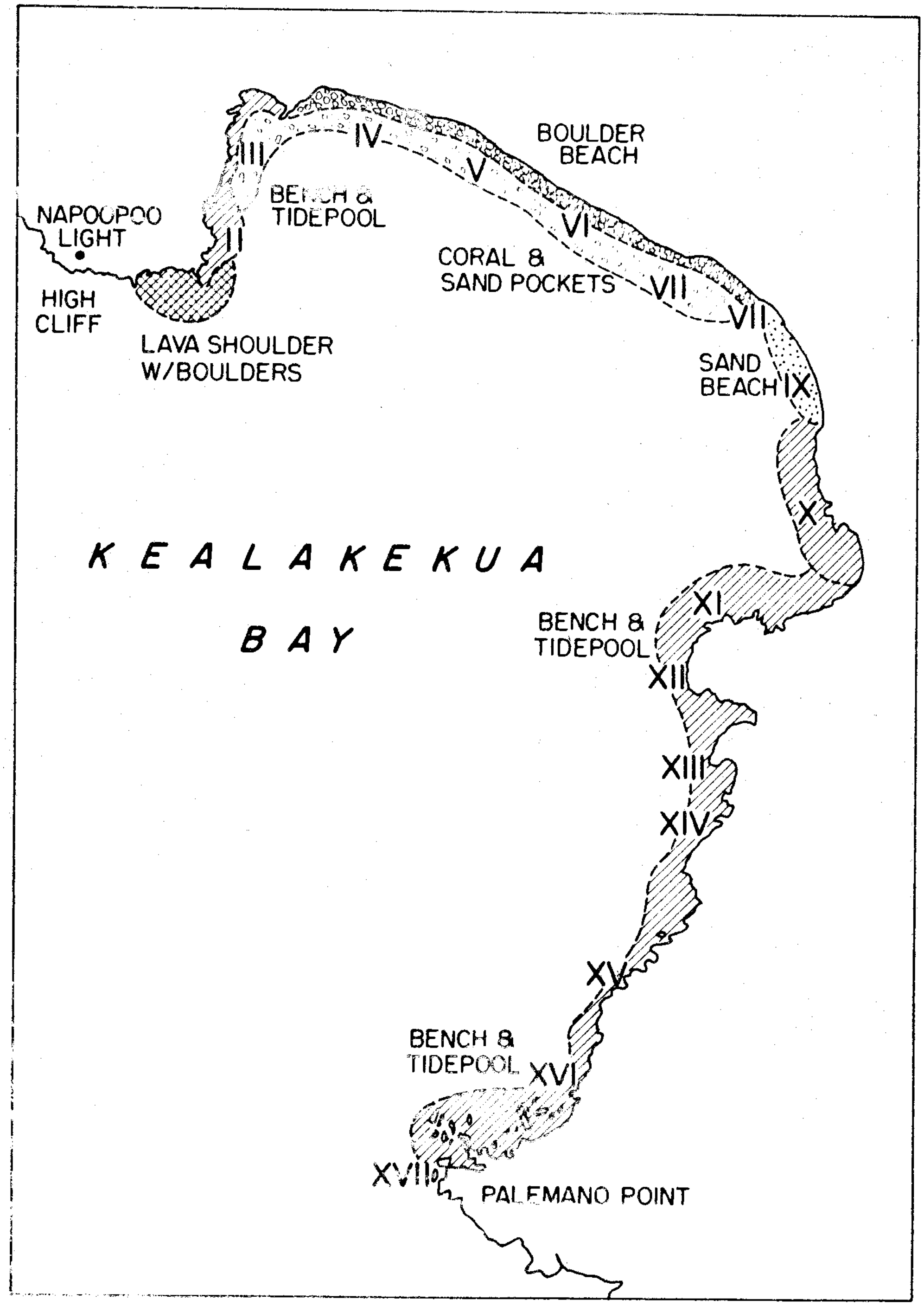


FIGURE 18. Diagram of molluscan habitats. Sections through the various habitats are indicated by Roman numerals.

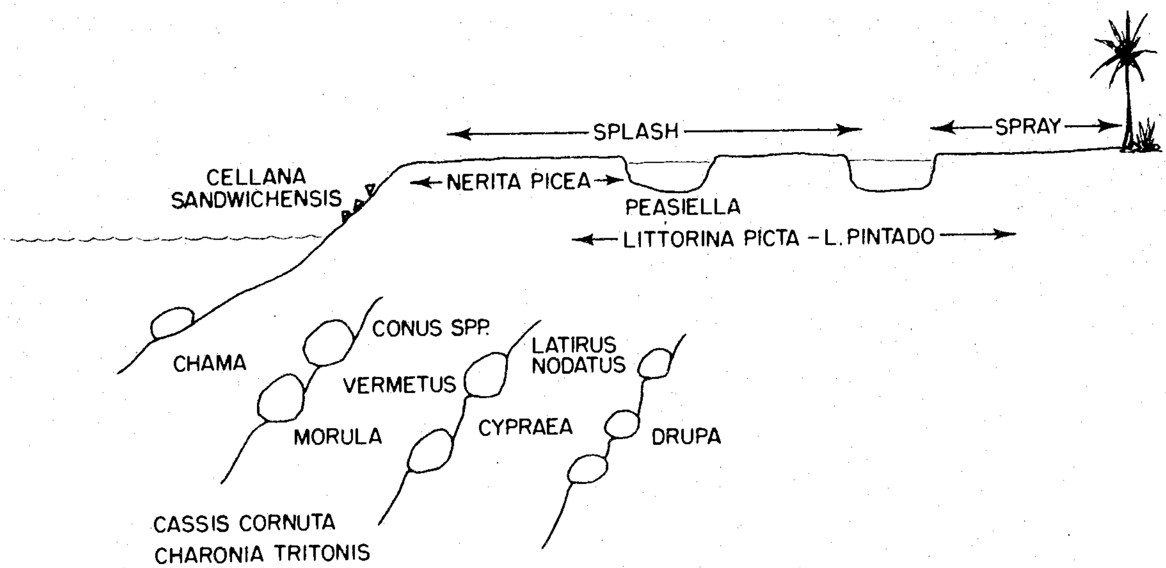


FIGURE 19. Section of Napoopoo cliff area (I).

and pahoehoe from Manini Beach to Palemano Point (Zones 10-16), excavated variously by shallow pools and narrow crevices. Four genera of snails are consistently found in the splash zone, and all are more closely tied to the ocean than are the snails of the spray zone because of the occurrence of pelagic veliger larvae during their life histories. The genera are _Littorina_, _Peasiella_, _Nerita_ and _Siphonaria_.

Two littorines (_Littorina picta_ and _L. pintado_) are found on the surface of the substrate, and the shoreward fringes of their populations may encroach on those of _Melampus_ and _Pedipes_ in the spray zone. The densities of the littorines are estimated as approximating 864/m^2. The small trochid-like littorinid, _Peasiella tantilla_, occurs in pools or damp crevices within the zone. These high pools appear to be subject to high temperatures and high salinities. Seaward of the littorines is the pipihi, _Nerita picea_, and the pulmonate limpet, _Siphonaria normalis_. Neritid densities are estimated as approximating 572/m^2, and those of _Siphonaria_ less than 200/m^2. Both _Nerita_ and _Siphonaria_ move with the tide; _Nerita_ moving shoreward just ahead of the incoming tide and seaward as the water recedes, while individuals of _Siphonaria_ become active but move only short distances. Another snail found in lesser densities with the nerite and the pulmonate limpet is the boring muricid, _Nucella harpa_, which drills in shells of both _Nerita_ and _Siphonaria_.

Intertidal Cliffs and Benches

EXPOSED HIGH CLIFFS. The cliffs or bluffs comprising Cook Point rise some 15 feet or more above mean sea level. The seaward face of these cliffs is covered with pink corraline algae. It receives not only the full force of waves entering the bay, but is subject to water cover at tides greater than one foot. Only one mollusc was seen on the cliff face, the opihi, Cellana sandwichensis. Its density was $68/m^2$. Associated with it is the shingle urchin, Colobocentrotus, in even greater densities.

SEA-LEVEL SHORELINES. The basalt shoreline which fringes the bay at sea level from the south corner of Cook Point to a point north of Cook's Monument, and north from Manini Beach to Palemano Point, is also subject to wave action and to water coverage at high tides. However, it is characterized by a more diverse biota than are the cliffs. Opihi is again the dominant mollusc in this habitat, but is present in far fewer numbers than on the cliff face. Other snails in this area include the carnivorous muricids, Nucella harpa, Thais intermedia, Morula granulata and Drupa ricina; the pulmonates, Siphonaria normalis and Onchidium; and the opisthobranch, Smaraghinella calyculata. At night the crevices and overhanging edges of this shoreline abound with three cowries: the humpback (Cypraea mauritiana), the reticulate cowry (C. maculifera) and the snakehead (C. caputserpentis).

TIDEPOOLS. The sea-level shoreline described above extends shoreward as a series of benches for distances of from 10 to 50 feet. These benches are studded with tidepools which vary in size, exposure and biota. South of Cook's Monument (Fig. 20) they in general support a less abundant and less diverse biota than do those (Fig. 24) north of Manini Beach Point.

The shoreward pools are diluted by fresh water, especially those near Cook's Monument (Fig. 21) which encroach on the strand. These

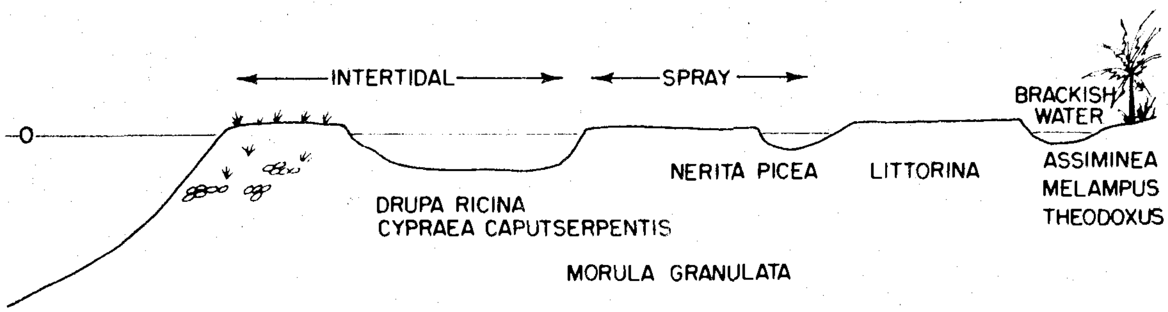


FIGURE 20. Section of bench and tidepool area (II).

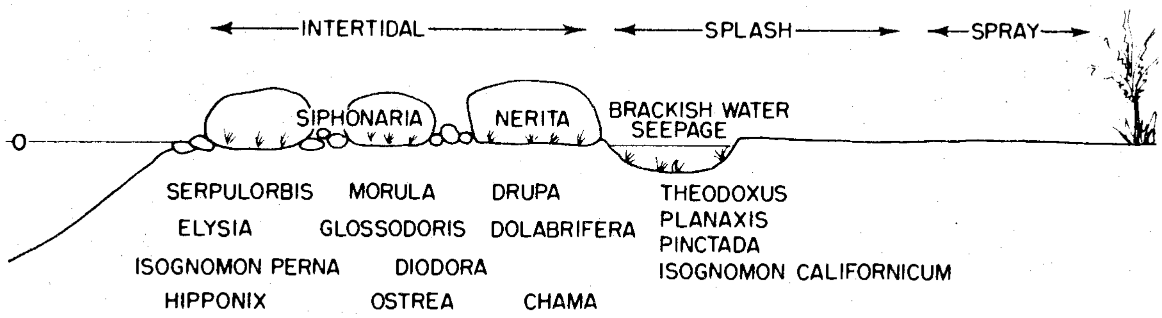


FIGURE 21. Section of boulder-bench shoreline (III).

pools are inhabited by a characteristic molluscan fauna: the nerite (or pipihi), Theodoxus neglectus, the clusterwink (also pipihi), Planaxis labiosa, and the bivalves, Pinctada margaritifera and Isognomon californicum. Shoreward saline pools are inhabited principally by nerites and hermit crabs.

The seaward tidepools are richer than high shoreward pools, harboring a diversity of algae and micromolluscs in addition to larger snails such as Cypraea caputserpentis, Morula ochrostoma and M. granulata. Sessile snails are also a component of the pools. For example, the bivalve, Chama iostoma, is easily recognized by its massive white shell, the left valve of which is cemented to the substratum. Worm shells of the genus Serpulorbis stud the substrate of the pools, trailing mucous threads from the apertures of their shells.

The undersurfaces of loose rocks in the tidepools support a more colorful and diverse fauna than is found on the surfaces, for here are found the sponge-feeding opisthobranchs, Dendrodoris nigra and Glossodoris lineata; the algal-feeding sacoglossan, Elysia; the white bivalve, Isognomon perna; and micromolluscs such as Triphora and some turrids.

Subtidal Reaches of the Bay

The richness of the subtidal reaches of Kealakekua Bay with respect to large, showy molluscs was spectacularly demonstrated during a three-day field trip in October, 1968. With little effort handsome specimens of Cypraea tigris, Charonia tritonis and Cassis cornuta were found in the bay at depths of less than 25 feet. These molluscs represent but a small fraction of a diverse and abundant fauna occurring within the bay.

CORAL-SAND RIDGES. On the extensive coral-sand shoulders which project seaward at a gentle angle from the cliffs and benches of Cook Point (Fig. 19), a rich assortment of molluscs studs the substrate: the sessile gastropods, Vermetus and Serpulorbis; the bivalve, Chama; the mobile carnivores, Conus distans, C. miles, C. ebraeus; and C. rattus, Latirus nodatus and C. teres. Intensive collection in this area should provide many more small but colorful epifaunal gastropods and bivalves.

CORAL FAUNA. The coral fauna of the bay was not studied directly as no dredging activities were attempted. An indirect method of estimating both the diversity and density of the molluscan fauna associated with coral and the niches provided by coral growths is to sample sand pockets occurring among the coral heads and coral-covered boulders. These sand pockets act as traps, and within their confines are found a variety of both living and non-living molluscs.

From a sand pocket 50 yards off Cook's Monument at a depth of 20-30 feet (Fig. 22), an estimated $0.25m^3$ of sand yielded 3,107 molluscs representing about 135 species, most 6 mm or less in length. The majority were epifaunal species and are presumed to live in niches in the area, such as on boulders and in coral.

SAND. The sand pockets described above also support a community of sand-dwelling organisms. In the pocket analyzed above were three species of Terebra (T. affinis, T. argus and T. guttata), Conus pulicarius, Cerithium granifera and the bivalve, Pinguitellina. These molluscs occur at densities from 0.1 to $0.5/m^2$; and a variety of other

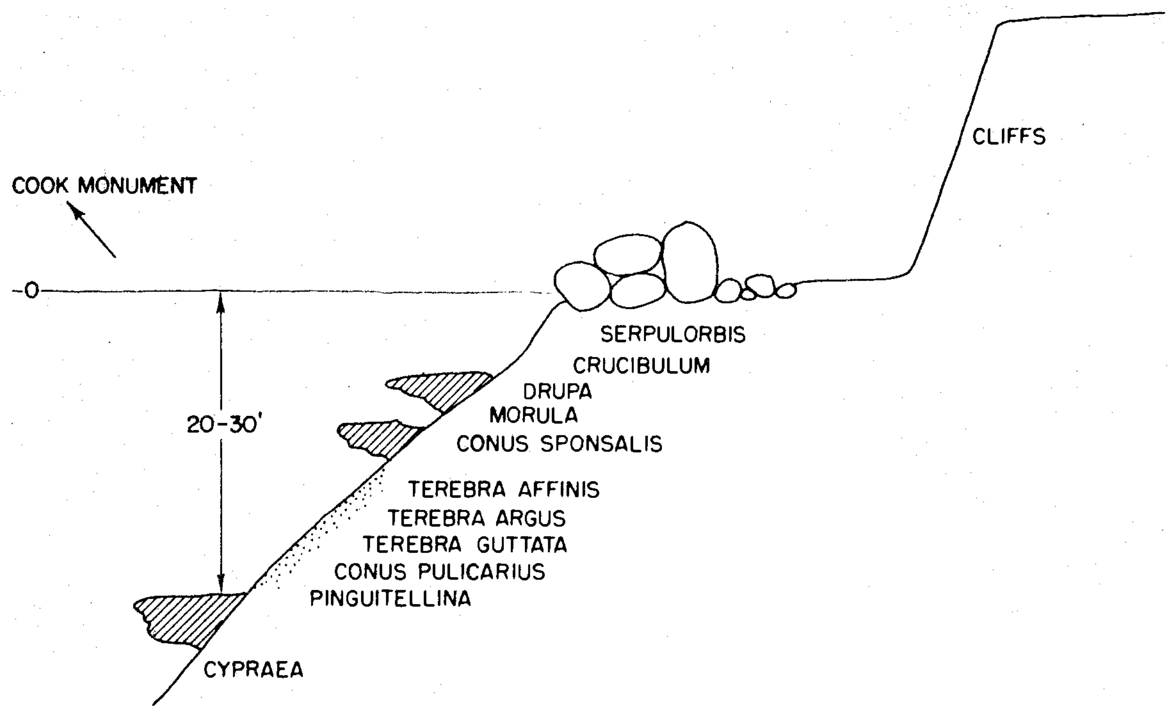


FIGURE 22. Section of subtidal coral-sand to boulder beach (IV - VII).

sand-dwelling molluscs ranging from two to six mm in length were also found, representing six species of prosobranchs, eight opisthobranchs and nine bivalves.

An even more diverse sand community with greater densities was found in the surf zone at Napoopoo Beach (Fig. 23). Here the community consists of four species of Terebra (T. inconstans, T. strigilata, T. penicillata and T. hectica), the polychaetes on which the terebrids feed and a variety of other invertebrates and vertebrates, including crabs (Emerita and Ocypode), a portunid (Gammarus) and a flounder.

Summary and Conclusions

The most noteworthy feature of the marine molluscan fauna of Kealakekua Bay from the standpoint of general interest is its diversity, the densities exhibited by some species, and the occurrence of some of the more spectacular molluscs in relatively shallow water. These features are, of course, enhanced by the sparkling, clear waters and exceptional visibility in the bay.

The diversity of marine molluscs is probably associated with both diversities in habitats and conditions of the bay, and with the unsilted waters; an area of approximately comparable habitat diversity but with silty water is Kaneohe Bay, Oahu. Here, 110 marine molluscan species are now found, which compares (Table 6) with 183 in Kealakekua Bay. The shallow-water habitat of some of the more handsome marine molluscs appears to be a phenomenon generally characteristic of the Island of Hawaii. However, sufficient data (Kay, 1961) are available for only Cypraea tigris. They indicate that tiger cowries are found in progressively shallower waters around the islands from Kauai to Hawaii.

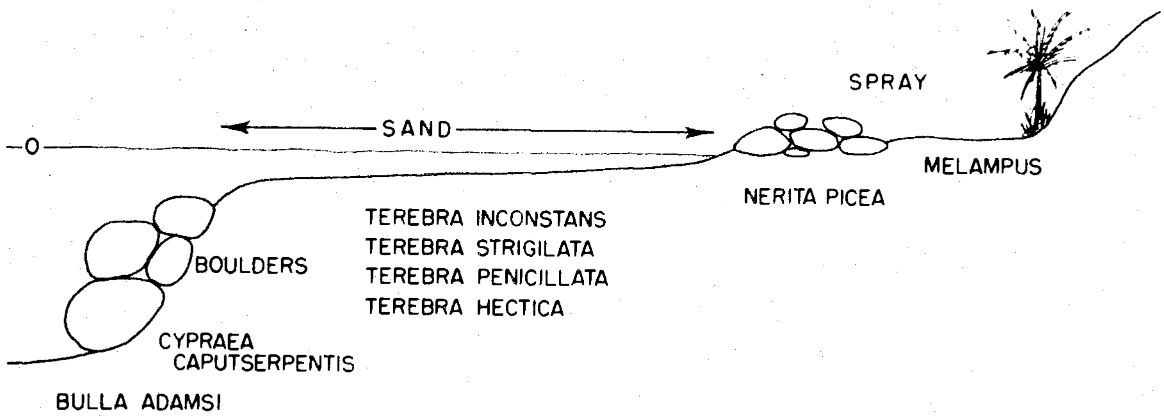


FIGURE 23. Section from Napoopoo Beach (X).

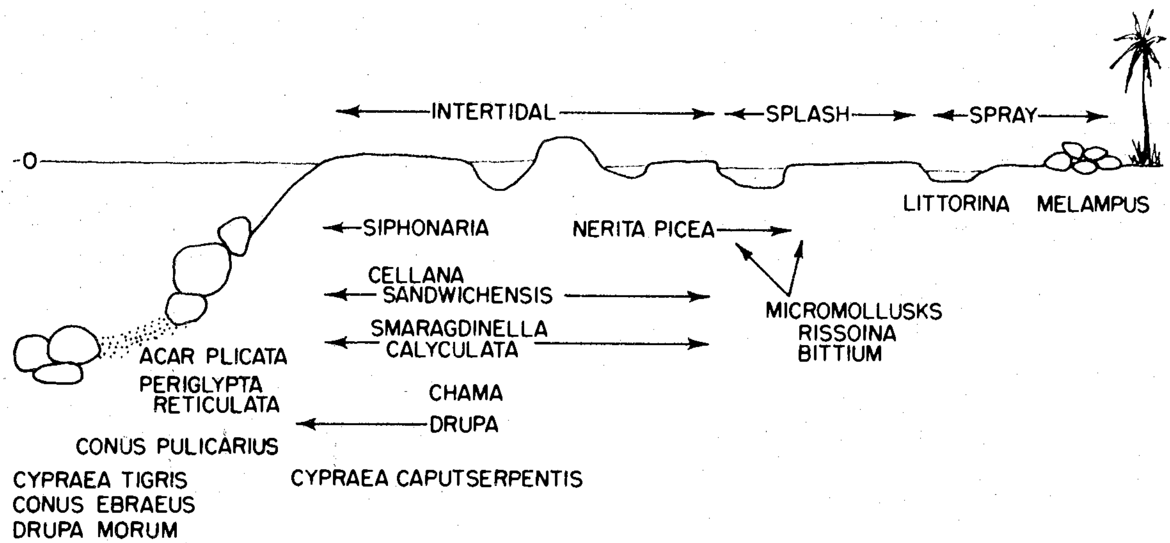


FIGURE 24. Section of bench and tidepools (XI).

TABLE 6 . Marine molluscs recorded from Kealakekua Bay in October, 1968.

	Spray-splash	Inter-tidal	Subtidal epifaunal	Sand	Brackish
GASTROPODA					
PROSOBRANCHIA					
Fissurellidae					
Diodora granifera			x		
Tugali oblonga			x		
Patellidae					
Cellana sandwicensis		x			
Cellana talcosa		x			
Trochidae					
Euchelus gemmatus			x		
Gibbula marmorea			x		
Thalotia rubra			x		
Trochus sandwichensis		x	x		
Turbinidae					
Leptothyra candida		x			
Leptothyra rubricincta			x		
Turbo sandwichensis			x		
Phasianellidae					
Phasianella variabilis			x		
Neritidae					
Nerita picea	x				
Nerita polita		x			
Theodoxus neglectus					x
Phenacolepadidae					
Phenacolepas scobinata			x		
Littorinidae					
Littorina picta	x				
Littorina pintado	x				
Peasiella tantilla	x				
Rissoinidae					
Rissoina ambigua			x		
Rissoina miltozona			x		
Rissoina turricula			x		
Zebina tridentata			x		

TABLE 6 (continued)

	Spray-splash	Inter-tidal	Subtidal epifaunal	Sand	Brackish
Architectonidae					
Heliacus implexus			x		
Planaxidae					
Planaxis labiosa					x
Modulidae					
Modulus tectum			x		
Vermetidae					
Serpulorbis sp.		x	x		
Vermetus sp.		x	x		
Cerithiidae					
Bittium zebrum			x		
Cerithium atromarginatum			x		
Cerithium columna			x		
Cerithium articulatum				x	
Cerithium pharos				x	
Cerithium nesioticum			x		
Cerithium sp. A			x		
Plesiotrochus souverbianus			x		
Triphoridae					
Triphora cingulifera			x		
Triphora clavata			x		
Triphora incisa			x		
Triphora trilirata			x		
Triphora sp. A			x		
Triphora sp. B			x		
Triphora sp. C			x		
Triphora sp. D			x		
Triphora sp. E			x		
Triphora sp. F			x		
Epitoniidae					
Epitonium sp. A			x		
Eulimidae					
Balcis sp.			x (on Holothuria atra)		
Subularia metcalfei			x		
Stilifer mittrei			x (on Heterocentrotus mammillatus)		
Fossaridae					
Fossarus garrettii			x		
Vanikoridae					
Vanikoro sp.			x		

TABLE 6 (continued)

	Spray-splash	Inter-tidal	Subtidal epifaunal	Sand	Brackish
Hipponicidae					
<u>Cheilea dillwynii</u>			x		
<u>Hipponix australis</u>			x		
<u>Hipponix folicaeus</u>			x		
<u>Hipponix grayanus</u>			x		
<u>Hipponix pilosus</u>			x		
Calyptraeidae					
<u>Crucibulum spinosus</u>			x		
Eratoidae					
<u>Erato sandwicensis</u>			x		
<u>Trivia edgari</u>			x		
<u>Trivia exigua</u>			x		
<u>Trivia hordacea</u>			x		
Cypraeidae					
<u>Cypraea caputserpentis</u>		x	x		
<u>Cypraea helvola</u>			x		
<u>Cypraea fimbriata</u>			x		
<u>Cypraea isabella</u>			x		
<u>Cypraea maculifera</u>		x	x		
<u>Cypraea mauiensis</u>			x		
<u>Cypraea maruitiana</u>		x	x		
<u>Cypraea moneta</u>		x	x		
<u>Cypraea teres</u>			x		
<u>Cypraea tigris</u>			x		
<u>Cypraea poraria</u>			x		
Strombidae					
<u>Strombus maculatus</u>				x	
Naticidae					
<u>Natica marochiensis</u>				x	
<u>Polinices</u> sp.				x	
Cymatiidae					
<u>Cymatium pileare</u>			x		
<u>Cymatium nicobaricum</u>			x		
<u>Charonia tritonis</u>			x		
Cassididae					
<u>Cassis cornuta</u>			x		
Magilidae					
<u>Coralliophila</u> sp.			x		

TABLE 6 (continued)

	Spray-splash	Inter-tidal	Subtidal epifaunal	Sand	Brackish
Muricidae					
Aspella sp.			x		
Thaisidae					
Drupa morum			x		
Drupa ricina		x			
Drupa rubusidaeus			x		
Morula granulata		x			
Morula ochrostoma		x			
Morula uva			x		
Nucella harpa		x			
Purpura aperia		x			
Thais intermedia		x			
Thaisid sp.			x		
Buccinidae					
Cantharus farinosus			x		
Engina sp. A			x		
Engina sp. B			x		
Pisania sp.			x		
Marginellidae					
Volvarinella pumila			x		
Pyrenidae					
Anarithma metula			x		
Euplica varians			x		
Mitrella fusiformis			x		
Mitrella margarita			x		
Mitrella sp.			x		
Fasciolariidae					
Latirus nodatus			x		
Mitridae					
Mitra litterata			x		
Turridae					
25 species			x		
Conidae					
Conus abbreviatus				x	
Conus catus			x		
Conus chaldaeus			x		
Conus distans			x		
Conus ebraeus			x		
Conus flavidus			x		

TABLE 6 (continued)

	Spray-splash	Inter-tidal	Subtidal epifaunal	Sand	Brackish
Conidae (continued)					
Conus lividus			x		
Conus miles			x		
Conus moreleti			x		
Conus publicarius				x	
Conus vitulinus			x		
Terebridae					
Terebra affinis				x	
Terebra argus				x	
Terebra felina				x	
Terebra guttata				x	
Terebra hectica				x	
Terebra inconstans				x	
Terebra penicillata				x	
Terebra strigilata				x	
OPISTHOBRANCHIA					
Pyramidellidae					
Odostomia sp.			x		
Otopleura mitralis				x	
Pyramidella sp.				x	
Actaeonidae					
Bullina scabra				x	
Pupa thaanumi				x	
Hydatinidae					
Haminoea sp.				x	
Bullidae					
Bulla adamsi				x	
Cryptophthalmidae					
Smaragdinella calyculata		x			
Atyidae					
Atys semistriata				x	
Elysiidae					
Elysia reticulata		x			
Juliidae					
Julia exquisita			x		

TABLE 6 (continued)

	Spray-splash	Inter-tidal	Subtidal epifaunal	Sand	Brackish
Aplysiidae					
Aplysia parvula		x			
Dolabrifera dolabrifera		x			
Dorididae					
Hypselodoris lineata		x			
Dendrodorididae					
Dendrodoris nigra		x			
Pleurobranchidae					
Umbraculum sp.		x			
PULMONATA					
Onchididae					
Onchidium sp.		x			
Ellobiidae					
Laemodonta bronni	x				
Melampus sp.	x				
Pedipes sandwichensis	x				
Siphonariidae					
Siphonaria normalis	x				
BIVALVIA					
Arcidae					
Acar plicata			x		
Mytilidae					
Hormomya crebristriatua			x		
Pteriidae					
Pinctada margaritifera		x			
Isognomoniidae					
Isognomon californicum					x
Isognomon perna		x			
Ostreidae					
Ostrea hanleyana		x			

TABLE 6 (continued)

	Spray-splash	Inter-tidal	Subtidal epifaunal	Sand	Brackish
Chamidae					
Chama iostoma		x	x		
Lucinidae					
Ctena bella				x	
Spondylidae					
Spondylus sp.			x		
Kellidae					
Nesobornia ovata			x		
Cardiidae					
Hemicardium mundum			x		
Mactridae					
Mactra thaanumi				x	
Tellinidae					
Macoma sp.				x	
Pinguitella nucella				x	
Cadella sp.				x	
Tellina sp.				x	
Tellina sp.				x	
Veneridae					
Periglypta reticulata				x	
Pectinidae					
Pecten sp.			x		

Several features exhibited by the marine molluscs of Kealakekua Bay are of more specialized interest. More data are needed to confirm the initial observations, but some trends are indicated.

1) In terms of percentage composition of species, the proportion of gastropods to bivalves (89:11 - Table 7) appears to be higher in Kealakekua Bay than it is elsewhere in the Hawaiian Islands. The over-all proportion is 82:18; in Kaneohe Bay, Oahu, it is 80:20.

2) Both the densities and species composition of sand communities in Kealakekua Bay appear to be richer than at least those of Oahu; in Kaneohe Bay, for example, the sand communities are comprised of about half as many molluscan species and the density of each species is considerably less than that in Kealakekua Bay.

3) The species diversity among the micro-molluscs appears to be largely attributable to molluscs characteristic of subtidal areas rather than those characteristic of tidepools and intertidal benches. As a result, several epifaunal gastropods such as _Leptothyra verruca_, _Gibbula marmorea_, _Synaptocochlea concinna_ and _Bittium parcum_ which are the dominant elements in the molluscan fauna at Poipu Beach, Kauai and Nanakuli, Oahu, are virtually absent from Kealakekua Bay, while the variety of small members of the family Turridae in the bay appears to be quite remarkable.

4) Another noteworthy absence from the molluscan fauna of the bay is that of representatives of the opisthobranch family, Pyramidellidae; but the lack of these snails is not so easily accounted for as that of the tidepool molluscs. Pyramidellids are parasitic on other molluscs, worms, etc., and their shells comprise an important

TABLE 7. Gastropod-bivalve ratios

	No. of species Gastropods	Bivalves	%
Kealakekua Bay	164	19	89 : 11
Kaneohe Bay, Oahu	91	23	80 : 20
All-Hawaii	719	150	82 : 18

component of drift at Poipu, Kauai and Nanakuli, Oahu.

5) The subtidal species of Conus also appear to be of interest. *Conus flavidus* and *C. lividus* were recorded as the two most abundant species on subtidal coral reefs in the Hawaiian Islands by Kohn (1959a) who based his results on studies on Oahu and Maui. At Kealakekua Bay, random but not quantitative sampling indicates that *C. miles*, a species not even listed among the ten most commonly found species by Kohn (*loc. cit.*) and reported as "rare" at depths of one to several fathoms (Kohn, 1959b), appears to be at least one of the most abundant, if not the most abundant cone occurring within the subtidal reaches of the bay.

Chapter 9

SEA URCHINS

(A quantitative survey of the echinoid fauna)

During eight days in early August and October, 1968, an expedition from the University of Hawaii examined the distribution and abundance of sea urchins in two bays along the Kona (leeward) coast of the Island of Hawaii: Kealakekua Bay (19° 28' N; 155° 55' W.) and Honaunau Bay (19° 25' N; 155° 55' W.). Kealakekua was the larger of the two bays and was where the major effort of the expedition was expended. The expedition was part of a larger program to survey the existing biota of Kealakekua. Information that is being gathered during this program will form a base-line to be used to assess changes that may be brought about by human activities both by tourists and by those living along the shores. Presently, there is a single small village, Napoopoo, on Kealakekua plus a small number of residences at the middle and south ends of the bay. The north end, by Captain Cook Monument, is uninhabited. Honaunau Bay has a small village, Honaunau, and the City of Refuge National Historical Park. Bay related activities of people living around the bays consist of fishing, principally with nets and hand-lines, and domestic-waste pollution. Some sea urchins are taken for food but not in great numbers. Tourist activities involving the animals are collecting slate-pencil urchins, _Heterocentrotus mammillatus_, for their spines and removing snails and small coral heads. Tourists are concentrated in Kealakekua Bay at Captain Cook Monument. Boats bring visitors from Kailua-Kona. During the summer months, two boats make two trips per day and carry up to 120 people per boat trip. Honaunau has no tourist boats and so possibly is not used as extensively. The area near Cook's Monument was selected for intensive sampling because of the high tourist density.

Statistical analysis was done at the University's Statistical and Computing Center on an IBM System 360/50. Computer time was supported by funds from the computing center. Development of survey techniques was supported by a Summer Research Initiation Award from the Office of Research Administration, University of Hawaii.

Methods

Urchin densities in Kealakekua were anticipated to be less than 1 animal per meter squared. On this assumption, it was felt that an appropriate quadrat size would have to be so large that it would be cumbersome to the divers or would have to be constructed at each sampling site. For this reason, a plotless method was selected in preference to the use of quadrats. The quarter method of forest sampling (Cottom and Curtis 1956) was modified to be used underwater by divers with SCUBA. A concrete block or smooth lava stone (ca. 7 kg) was used as the body of the sampling device. A cross of orange glolite tape (such as used by construction survey teams) was attached to the block either with epoxy glue or small concrete-studs. A threaded stud was driven into the center of the cross and a snap-swivel placed over the stud. A nut and washer prevented the swivel from coming off but the nut was not tightened to the extent that the swivel could not move freely around the stud. A 50 foot stainless steel tape was attached to the snap. Underwater, a diver measured and recorded the distance to the nearest sea urchin and its species in each quarter. Data was written on plastic slates. Plastic is available from Transparent Products Corporation, 1727-43 W. Pico Boulevard, Los Angeles, California 90015 as #VS-5300-08 pp matte on both sides, 0.02" thick, white plastic, and is available in 20" x 40" sheets that are easily cut. Three divers were used and generally each was able to measure between 8 and 13 points. Initial points were selected at random at the deepest portion of the transect. Subsequent points were taken along a line towards shore at about 20-25' intervals. Densities were calculated by first summing all the individual distances without regard to species, determining the mean distance, standard deviation and standard error, and converting these into meters. The mean distance was then squared and this used to estimate the mean area which contains one urchin. Confidence intervals were determined by adding or subtracting one standard error from the mean and redetermining the mean area by squaring the result. For example, the mean distance off the breakwater at Napoopoo was 7.56 ± 0.69 feet.

$7.56 \pm 0.69 \quad \times \quad 0.3048 = 2.30 \pm 0.21$ meters

$2.30^2 = 5.31$ the mean distance squared

$(2.30 + 0.21)^2 =$ 6.32 the mean plus 1 SE squared

$(2.30 - 0.21)^2 =$ 4.39 the mean minus 1 SE squared

The reciprocals of each of these squares gives an estimate of the mean number of animals per meter squared plus or minus one SE of the mean of the distance measurements.

$1/5.31 = 0.19$ the mean

$1/6.32 = 0.16$

$1/4.39 = 0.23$

$\bar{x} = 0.19 + .04$ or $- .03$ animals per meter squared.

The number of each species per meter squared was calculated by multiplying the total density by the relative densities of the species. Relative density was defined as the number of a given species/total number of individuals in the sample. For a further discussion of the quarter method see Cottom and Curtis (1956).

The initial August survey indicated higher densities than originally anticipated so sampling in October was done with 1-meter square quadrats. Sampling procedure was to place the quadrat for the first sample at the lowest depth and then take the next sample by simply turning the quadrat over, advancing 1 meter up the slope. The result was a set of quadrats in the shape of a 1 meter wide transect from deep water to the shore.

Organisms

Edmondson (1946) lists 14 regular urchins as members of shallow water benthic assemblages of Hawaii. Eleven of these were found in Kealakekua and Honaunau Bays. The classification of Hyman (1955) is used.

Order Cidaroidea

Family Cidaridae

Chondreocidaris gigantea A. Agassiz

Eucidaris metularis (Lamarck)

Order Diadematoida

Family Diadematidae

Diadema paucispina A. Agassiz

Echinothrix calamaris Pallas

E. diadema (Linnaeus)

Family Toxopneustidae

Trioneustes gratilla (Linnaeus)

Family Echinometridae

Colobocentrotus atratus (L. Agassiz)

Echinometra mathaei Blainville

E. oblonga Blainville

Echinostrephus aciculatus A. Agassiz

Heterocentrotus mammillatus (Linnaeus)

Echinometra sp. and *Colobocentrotus* were not included in the quarter method of sampling in August but were included in the 1-m quadrat counts.

Areas

Four areas were examined within Kealakekua Bay and single sites were selected within Honaunau Bay and 1 mile south of Honaunau (Fig. 1).

Area 1. The first area was between Napoopoo light at Cook Point and Cook's Monument at the north end of Kealakekua Bay. This area and the transect 1 mile south of Honaunau were the most exposed sites that were sampled. The bottom sloped rapidly away from the shore with several vertical ledges of 15-20 feet. Near shore in the surf the rocks were relatively barren with only a few *Colobocentrotus*. At a depth of about 30' the bottom was covered with coral heads. Past this depth the bottom dropped rapidly to 28 fathoms. Three quarter method transects were run in this area and a single transect using quadrats. Transects were perpendicular to the shore and started at a depth of about 80 feet.

Area 2. The second area was in Kaawaloa Cove. The cove appeared to be very protected from waves which is also indicated by the fact that it is used for boat moorage during winter storms. Six quarter method transects were run: three in front of the monument (one directly off the monument and one on either side) and three south of the monument and off a dike (one transect directly off the dike and one on either side). Five quadrat transects were run from directly in front of the monument to the corner of the cove between the monument and the dike. As in the first area, the bottom dropped away rapidly. The rate of descent, however, was greater directly in front of the monument. The shallow waters, less than 4' deep were different in the two areas of the cove. The area off the dike was at the base of a tallus slope and was composed of large lava boulders that did not support a lush coral growth. Coral rubble with some living coral formed the bottom in the shallows in front of the monument. Below 4-5' there was living coral in both areas. At lower depths the two areas once again differed. Below about 30-40 feet off the monument most of the coral heads were dead but with living tips. The coral was principally *Porites compressa*. There was more living coral off the dike and *Porites pukoensis* was more abundant. According to one diver, more algae were present between the coral fingers in front of the monument. Generally there was more rubble in front of the monument. This possibly was the result of breakage caused by anchor chains.

Area 3. The third area was directly in front of the breakwater at Napoopoo. The bottom consisted of large coral heads separated by sand. Two quarter method transects were run at 100 and 200 feet from shore and parallel to it. Water depth was 10-20 feet.

Area 4. The fourth area was a lava rock shore in front of a cottage owned by T. Ashihara of Kealakekua, Hawaii. A single 17-point transect was run from about 300' offshore into a small cove in front of the cottage. Water depth was from ca. 30 to 5 feet. A short transect was run from the cove into 8 feet of water and animals were counted in quadrats at 4 depths. A total of 18 1/9-m^2 quadrats were counted.

Area 5. The fifth area was a protected shelf at Palemano Point at the south end of Kealakekua Bay. A lava flow has formed a flat area with rocks rising above the water surface. There were many shallow pools some of which were sandy. The plotless method was not used here but rather a 1-m quadrat was employed to sample a densely aggregated population of Tripneustes. A total of 30 quadrats was counted in 2-3 feet of water.

Area 6. The sixth area was in Honaunau Bay off a lava bench just north of the canoe landing at the village of Honaunau. The bottom was principally living coral. Depth ranged from 35 to 10 feet. The bottom sloped very gently downwards to about 300 feet from shore where it descended rapidly to 23 fathoms. Although the average slope was small, the bottom consisted of very large coral mounds separated by coral filled valleys so that locally there was high relief. Some of the mounds appeared to be dead. Sampling was initiated just shoreward of the dropoff. Three plotless transects were run perpendicular to the shore.

Area 7. The final sampling area was about 1 mile south of Honaunau Bay. A single transect using quadrats was run from 60 to 20 feet. The bottom was lava and the shore was exposed to the sea.

Results

In the analysis of urchins distribution and abundance, several parameters used in phytosociological description (Curtis and McIntosh 1950, 1951) were estimated which are defined as follows:

Relative frequency = number of occurrences of one species as a percentage of the total number of occurrences of all species.

Relative density = number of individuals of one species as a percentage of the total number of individuals of all species.

Relative dominance = total wet weight of one species as a percentage of the total wet weight of all species.

Importance Value (IV) = the sum of the relative frequency, density and dominance.

These relative values will be used to compare the species composition of different areas and are valuable in this comparative capacity in addition to the estimates of absolute density (number of individuals/meter squared).

Relative frequency and density were determined directly from the quadrat counts or from the points of the quarter method. Because individuals were not weighed when counted, certain calculations were required to estimate weight. Animals were collected at several locations to determine size structure of the populations. Sampling procedure was to attempt to collect as many animals from one location as possible. Numbers in a sample generally were about 100 individuals. It must be stressed that the size distributions represent animals exposed enough to be seen by a swimmer. This obviously introduces a bias in favor of large individuals and animals under 1 or 2 cm were probably inadequately sampled.

Size distributions (Figs. 25 and 26) were constructed for Heterocentrotus, Echinothrix calameris, Diadema and Echinometra in Kaawaloa Cove, for Tripneustes at Palemeno Point and for Heterocentrotus at Honaunau Bay. Sampling of Echinometra was different from other species in that it was measured in place in a series of 1-meter quadrats in the corner of Kaawaloa Cove. Echinometra lives in holes in the coral rock and is generally difficult to extract. The procedure was to use a vernier calipers underwater and to assign individuals to 1 cm size classes. The precision is not as great as with the other urchins. For a species where no size distribution was constructed, weights were approximated by assigning it the distribution of the urchin that most closely resembled it in size. Eucidaris and Echinostrephus were approximated by Echinometra and Chondreocidaris was approximated by Heterocentrotus. All dominance values were based on the size distributions indicated above. All Echinothrix populations were assumed to be like the one measured in Kaawaloa Cove, all Tripneustes populations were assumed to be like the one measured at Palemano Point, etc. The relative dominance values and importance values are subject to the errors inherent in these approximations. A problem developed in the underwater identification of Echinothrix so that there is doubt surrounding the actual field records. Both species were present but are lumped to avoid conveying inconsistencies.

Size distributions were converted into weights by first determining a mathematical expression that would relate wet weight to a linear measurement. A series of animals were weighed and

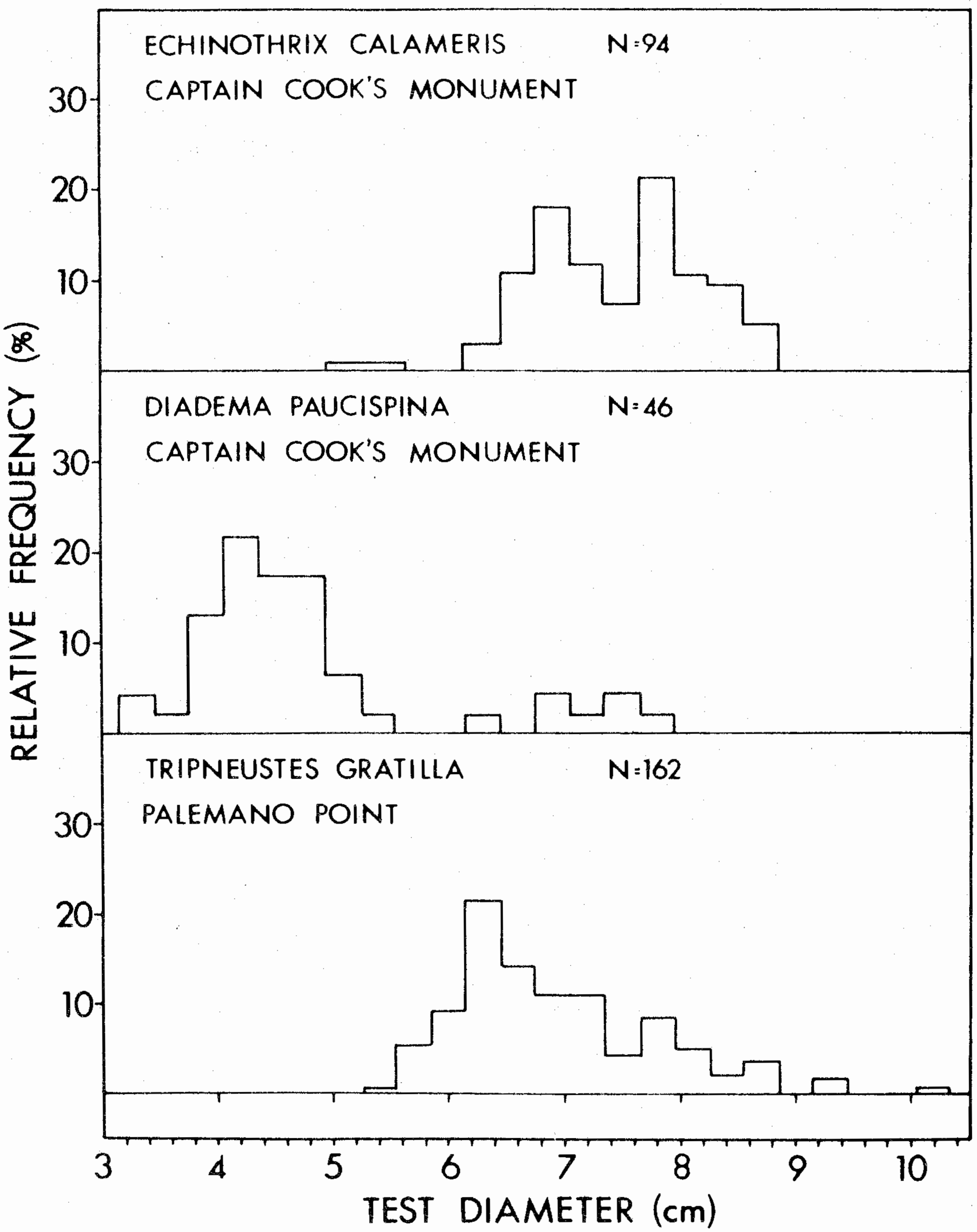


FIGURE 25. Relative frequency as a function of test diameter in selected urchin species.

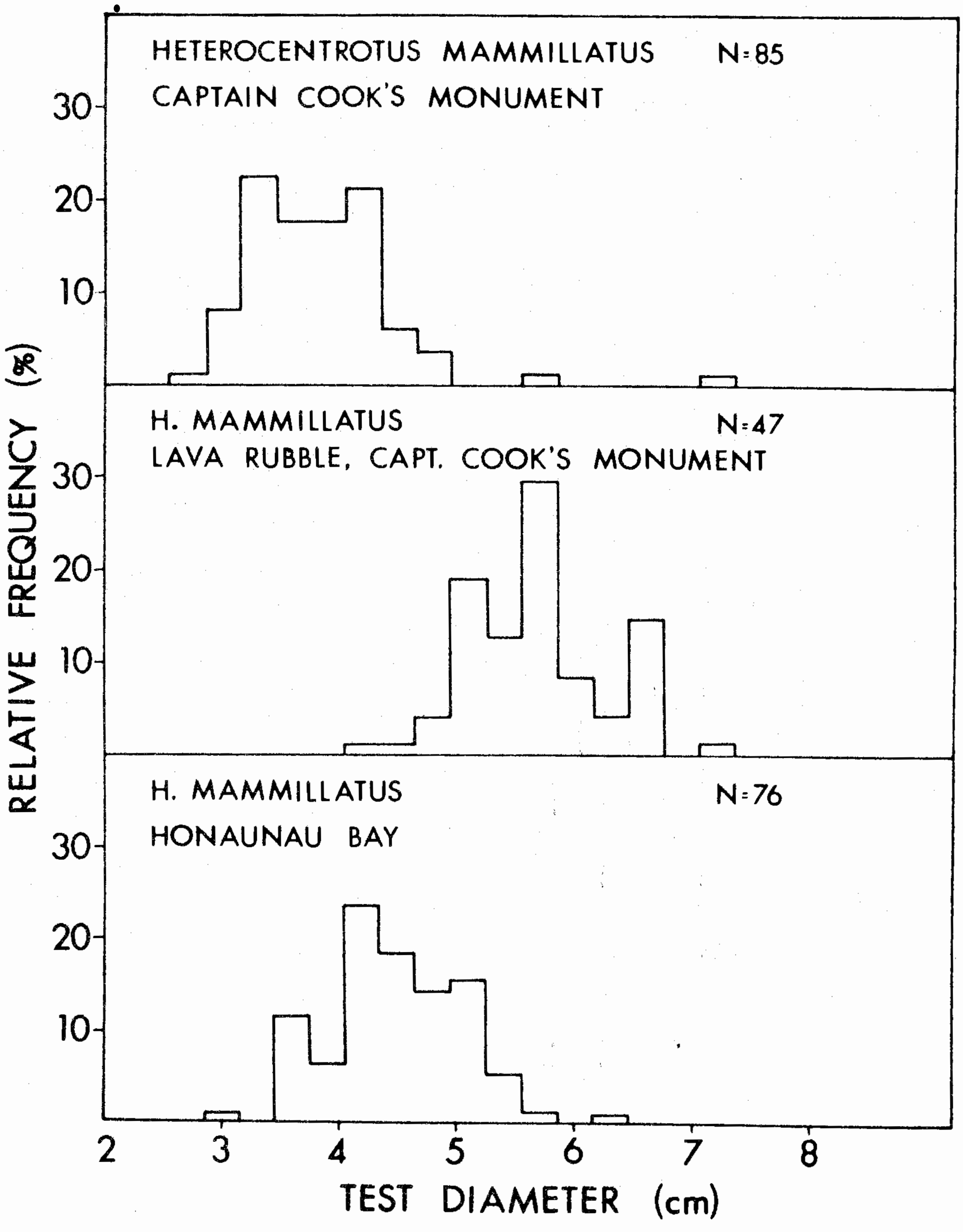


FIGURE 26. Relative frequency of the urchin, Heterocentrotus mammillatus, as a function of test diameter.

measured. Heterocentrotus came from Kealakekua Bay, Echinothrix diadema from Kapapa Island, Oahu, Tripneustes from Kaneohe Bay and Makua Beach, Oahu, and Echinometra mathaei from the Blowhole, Oahu.

Log-log plots of wet weight vs. diameter were not linear. It was discovered that the exponent required to raise a linear measurement to its wet weight was a function of that linear measurement but that the relationship was non-linear (Fig. 27). In Echinothrix and Tripneustes the exponent increased with increasing size. In Heterocentrotus the exponent decreased with increasing size. This appears to be related to the relative contribution of the spines to the total weight of an individual. In small Tripneustes and Echinothrix the spines appear to be relatively large in a small individual and relatively small in a large individual. The result is that a greater percentage of the total weight is made up of spines in a small animal and relatively less in a large individual. The opposite appears to be true in Heterocentrotus where small individuals have relatively less of their total weight made up by spines compared with large individuals where a great portion of the weight can be spines. The possibility of allometric relationships between test size and relative thickness or height vs. diamater can not be ruled out. These, however, were not examined and as a first approximation the role of the spines appears to be paramount. Tripneustes showed the least weight variation at a given size and Heterocentrotus showed the greatest variation. This again is probably related to the relative contribution of the spines to total weight. A single lost or broken spine in Heterocentrotus would change the weight more than removing all of the spines of a similar sized Tripneustes.

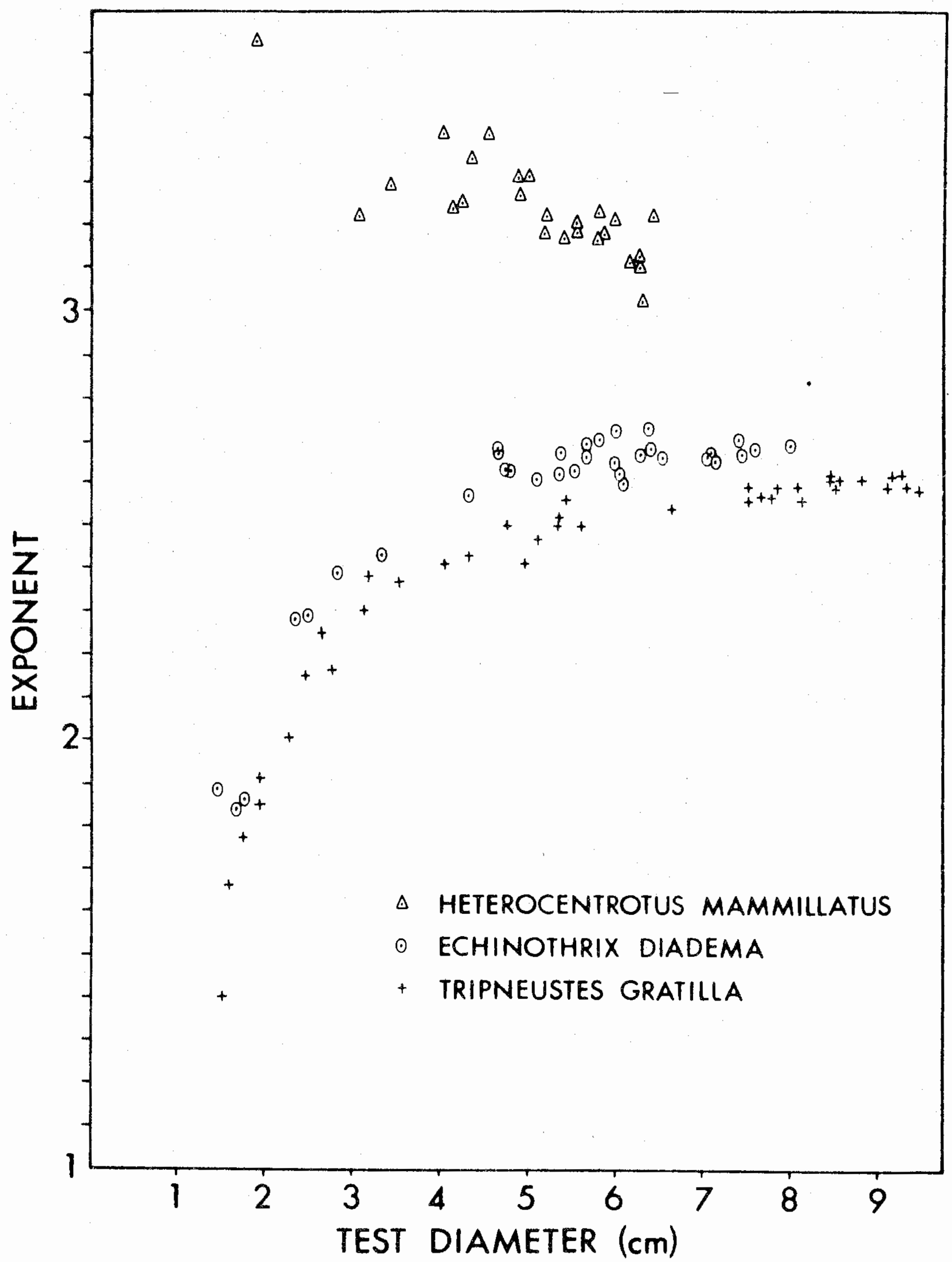


FIGURE 27. Exponent (x) required to convert urchin test diameter into wet weight in the expression, Wet Wt. = D^x.

Several methods were used to develop an expression that would describe the size dependent exponent. No single method was found that was satisfactory for all species. The "Walford method" (Ricker, 1952) of fitting growth data to the von Bertalanfy growth equation was used to approximate exponent values for a given size. Size classes were set up with a 1 cm interval and the mean exponent (x) at a diameter (d+1 cm) was plotted as a function of the exponent at size d. This is comparable to Walford's length at (t+1) as a function of length at time t. The maximum exponent determined in this manner was used as a trial value in the plot of $\ln(x_{max} - x_d)$ as a function of d. The straightness of such a plot is a function of the value selected for x_{max} (Ricker, 1952). X_{max} was adjusted to give the straightest line by a computer program that maximized the correlation coefficient. The constants derived from the regression of $\ln(x_{max} - x_d$ on d were used to write an expression relating the value of an exponent to the animal size. The general form of the expression is:

$$x_d = x_{max}\ (1 - e^{-K(d - d_o)}) \qquad (1)$$

and, to then determine wet weight in grams,

$$W_d = d^{xd} \qquad (2)$$

where W_d is wet weight at a given size and d is a linear measurement.

A second method of finding exponents was by selecting constants from a regression of $\log_{10} xd$ on loglog d.

$$W_d = d^{k(\log d)^b} \qquad (3)$$

A third method was by using constants from a regression of $\ln\ln W_d$ on lnln d.

$$W_d = e^{k(\ln d)^b} \qquad (4)$$

Generally, the best fit was obtained from expression 3 (Table 8). Echinometra was not treated by attempting to determine a general expression relating wet weight to size. The size distribution of Echinometra mathaei in Kaawaloa Cove had a small mean and small standard deviation (mean diameter = 2.4 + 0.7(SD) cm). It was felt that an adequate estimate of weight did not require the establishment of a general expression. Nine small Echinometra were collected from rocky pools near the Blowhole, Oahu. Size range was from 2.27 cm to 3.74 cm. Weight of an individual 2.4 cm was determined graphically and found to be 8.2 g. Average weight for the other species was found by calculating the weight of each class in the size distribution and multiplying this by the relative frequency of the class. The sum of weight times frequency for all classes is an estimate of the weight of an average individual and was used to estimate the weight of a given density of urchins and to calculate dominance values.

The initial stage of quarter data analysis was to combine distance measurements at the points into statistically homogeneous subsets of the entire sample. Because transects were made up physical clines (depth) in all but the Napoopoo breakwater transect an analysis procedure was selected that would permit separation of the transect x into subsets showing similar densities. Beginning at the bottom of the transects, distance measurements from adjoining pairs of points were pooled yielding subsets of 8 measurements each (4 measurements per point). For example, measurements from points 1 and 2 were pooled, those from points 3 and 4 were pooled, etc. The means of these subsets were then tested for homogeneity by analysis of variance. Where non-significance of difference (.05) was indicated

TABLE 8

Regression equations relating a linear test measurement (cm)* to wet weight(g). All animals were collected in August 1968.

Species	Area of Collection	N	Expression
Heterocentrotus mammillatus	Kealakekua Bay, Hawaii	26	$Wt = D^{3.063(\log D)-}$ $.1491$
Echinothrix diadema	Kapapa Island, Oahu	35	$Wt = D^{2.839(\log D)}$ $.2462$
			$Wt = D^{2.688(1-e^{-.769(D-.590)})}$
Tripneustes gratilla	Kaneohe Bay and Makua Beach, Oahu	307	$Wt = e^{2.194(\ln D)}$ 1.250
			$Wt = D^{2.620(\log D)}$ $.1482$

Equations are listed for each species in order of adequacy in relating wet weight to a linear measurement. Goodness of fit was determined by eye.

*greatest length measured in *Heterocentrotus*; diameter measured in *Tripneustes* and *Echinothrix*.

by Duncan's multiple range test (Walpole, 1968), the subsets were combined. This gave a single subset for the entire transect or the transect was broken into several homogeneous subsets. Obviously the sensitivity of the method to distinguish different densities along the transect was based on the variance within the original two point subsets.

Data gathered from quadrats was easier to process. In low density areas (Napoopoo Light and 1 mile south of Honaunau), the entire transect was treated as a single entity and density estimates represent means for the entire area. In this respect they are similar to the quarter method estimates for similar areas. In Kaawaloa Cove, quadrats were segregated by 5-foot depth intervals and the quadrats for the five transects were combined on this basis. Statistical analysis involved the calculation of means and standard errors of each 5-foot level.

A summary of densities determined by the quarter method are given in Table 9 . Relative values for both the quarter and quadrat methods are given in Table 10.

Area 1. Between Napoopoo Light and Kaawaloa Cove. Of all regions sampled by the quarter method, distances were greatest in this area. In some quadrants, no urchins could be found within a radius of 50 feet. In such a case, the value of 50 feet was assigned to the quarter and the species called "Blank." This region and the transects at Napoopoo breakwater were the only areas where blanks were recorded. Other areas properly fulfilled the requirements of the quarter method by having an urchin recorded for every quadrant. The means of the distance measurements of the 3 transects were not homogeneous by an analysis of variance ($F_{(2,81)} = 11.22$, $p < .01$). Means of two transects, however, formed a homogeneous subset by Duncan's least significant range test. The two transects that were combined bracketed the

TABLE 9 . Urchin density estimates based on the quarter method of sampling.

	Area	Subset*	Number of measurements	Distance (m) Mean ± 1 SE	Density** ($No./m^2$)
1.	Napoopoo Light	A	72	4.77 ± 0.56	.03 .04 .06
		B	12	11.7 ± 1.0	.006 .007 .009
2.	Kaawaloa Cove	A***	8	7.26 ± 2.32	.01 .02 .04
		B	16	2.08 ± 0.26	.20 .23 .30
		C	32	1.62 ± 0.17	.31 .38 .47
		D	4	3.61 ± 0.52	.06 .08 .10
		E	176	0.64 ± 0.03	2.22 2.45 2.73
		F	8	0.84 ± 0.16	1.01 1.43 2.16
		G	8	1.28 ± 0.16	.49 .61 .80
3.	Napoopoo Breakwater	A	76	2.30 ± 0.21	.16 .19 .23
4.	Ashihara Cottage	A	48	0.92 ± 0.10	.96 1.18 1.48
		B	20	1.86 ± 0.24	.15 .29 .72
5.	Honaunau Bay	A	92	0.68 ± 0.05	1.87 2.14 2.48
		B	40	0.96 ± 0.10	.99 1.08 1.25

*Subsets determined by analysis of variance and Duncan's multiple range test. Full explanation given in text.

**The mean is underlined and bracketed by estimates based on 1 SE of the mean distance. See text for sample calculation.

***Spatial relationship of the subsets in Kaawaloa Cove is shown in Figure 25 . Relationships of subsets in other areas is described in the text.

TABLE 10 . The importance value (IV) of major urchin species.

Area	Species	No. of quads. or points	No. of urchins	Total wet weight	Relative frequency	Relative density	Relative dominance	Importance value (IV)
1. Napoopoo Light (quarter) Subset A and Subset B	Heterocentrotus	16	33	3000	38.1	47.1	29.4	114.6
	Echinothrix	17	26	6700	40.5	37.1	65.5	143.1
	Tripneustes	4	4	464	9.5	5.7	4.5	19.7
	Eucidaris	3	5	41	7.1	7.1	0.4	14.6
	Echinostrephus	2	2	16	4.8	2.9	0.2	7.9
	TOTAL	42	70	10,221				
1. Napoopoo Light (quadrat)	Heterocentrotus	6	9	819	27.3	32.1	20.0	79.4
	Echinothrix	10	12	3108	45.5	42.9	75.9	164.3
	Tripneustes	1	1	116	4.5	3.6	2.8	10.9
	Eucidaris	2	3	25	9.1	10.7	.6	20.4
	Echinometra	3	3	25	13.6	10.7	.6	24.9
	TOTAL	22	28	4093				
2. Kaawaloa Cove (quarter) Subset B	Heterocentrotus	2	2	182	22.2	15.4	9.8	47.4
	Echinothrix	3	3	777	33.3	23.1	41.7	98.1
	Tripneustes	3	7	812	33.3	53.8	43.6	130.7
	Chondreocidaris	1	1	91	11.1	7.7	4.9	23.7
	TOTAL	9	13	1862				

TABLE 10 (continued)

Area	Species	No. of quads. or points	No. of urchins	Total wet weight	Relative frequency	Relative density	Relative dominance	Importance value (IV)
2. Kaawaloa Cove (quarter) Subset C	Heterocentrotus	6	13	1183	33.3	40.6	30.1	104.0
	Echinothrix	4	4	1036	22.2	12.5	26.3	61.0
	Tripneustes	7	14	1624	38.9	43.7	41.3	123.9
	Chondreocidaris	1	1	91	5.6	3.1	2.3	11.0
	TOTAL	18	32	3934				
2. Kaawaloa Cove (quarter) Subset E	Heterocentrotus	42	145	13,195	71.2	84.3	69.1	224.6
	Echinothrix	13	21	5439	22.0	12.2	28.5	62.7
	Tripneustes	1	2	232	1.7	1.2	1.2	4.1
	Eucidaris	1	1	8	1.7	.6	.0	2.3
	Chondreocidaris	1	1	91	1.7	.6	.5	2.8
	Diadema	1	2	142	1.7	1.2	.7	3.6
	TOTAL	59	172	19,107				
2. Kaawaloa Cove (quadrat)	Heterocentrotus	103	363	33,033	43.3	49.8	57.4	150.5
	Echinothrix	41	69	17,871	17.2	9.5	31.1	57.8
	Tripneustes	31	37	4292	13.0	5.1	7.5	25.6
	Eucidaris	9	10	82	3.9	1.4	0.0	5.3
	Echinometra	50	246	2017	21.0	33.7	3.5	58.2
	Diadema	3	3	231	1.3	.4	.4	2.3
	Echinostrephus	1	1	8	.4	.1	0.0	0.6
	TOTAL	238	729	57,534				

TABLE 10 (continued)

Area	Species	No. of quads. or points	No. of urchins	Total wet weight	Relative frequency	Relative density	Relative dominance	Importance value (IV)
3. Napoopoo Breakwater (quarter)	Heterocentrotus	19	55	5005	61.3	77.5	60.4	199.2
	Echinothrix	8	10	2590	25.8	14.1	31.2	71.1
	Tripneustes	4	6	696	12.9	8.4	8.4	29.7
	TOTAL	31	71	8291				
4. Ashihara Cottage (quarter) Subset A	Heterocentrotus	12	46	4186	85.7	95.8	94.0	275.5
	Echinothrix	1	1	259	7.1	2.1	5.8	15.0
	Eucidaris	1	1	8	7.1	2.1	.2	9.4
	TOTAL	14	48	4453				
4. Ashihara Cottage (quarter) Subset B	Heterocentrotus	5	13	1183	55.6	65.0	41.5	162.1
	Echinothrix	3	6	1554	33.3	30.0	54.5	117.8
	Tripneustes	1	1	116	11.1	5.0	4.1	20.2
	TOTAL	9	20	2853				
6. Honaunau Bay (quarter) Subset A	Heterocentrotus	23	90	12,240	95.8	97.8	95.9	289.5
	Echinothrix	1	2	518	4.2	2.2	4.1	10.5
	TOTAL	24	92	12,758				
6. Honaunau Bay (quarter) Subset B	Heterocentrotus	10	37	5032	83.3	92.5	86.6	262.4
	Echinothrix	2	3	777	16.7	7.5	13.4	37.6
	TOTAL	12	40	5809				

TABLE 10 (continued)

Area	Species	No. of quads. or points	No. of urchins	Total wet weight	Relative frequency	Relative density	Relative dominance	Importance value (IV)
7. One mile south of Honaunau (quadrat)	Heterocentrotus	4	9	819	33.3	45.0	52.6	130.9
	Tripneustes	4	6	696	33.3	30.0	44.7	108.0
	Eucidaris	1	1	8	8.3	5.0	0.5	13.8
	Echinometra	3	4	33	25.0	20.0	2.1	47.1
	TOTAL	12	20	1556				

statistically different transect. The variation between the two subsets accordingly cannot be attributed to a cline. The larger subset contained 72 distance measurements with 14% "Blanks." The smaller subset contained 12 measurements and had 33% "Blanks." To test for randomness of urchin distribution, the distance measurements for each subset were taken and a frequency distribution constructed using 1-foot intervals. The resulting distributions were tested against a Poisson distribution with the same mean using a Chi^2 test. The 72 value subset did not approximate a Poisson at the .01 level of significance ($X^2 = 73.3$, $p < .01$). The variance-mean ratio was 16.9 indicating a high degree of aggregation. The 12 value subset with its observed mean had insufficient data to test against a Poisson using 1' intervals. Its variance-mean ratio was 3.7, again indicating aggregation. Estimates of density for the two subsets are .04 + .02 or -.01 urchins per meter squared for the 72 point subset and .007 + .002 or -.001 per m^2 for the 12 value subset (Table 8). Density estimated from the quadrat method is higher. The single transect off the lighthouse gave $.67 \pm .24/m^2$ not considering Echinometra and $.83 \pm .27/m^2$ counting Echinometra. Aggregation, however, was still indicated with a variance-mean ratio of 2. The relative "Importance values" (Table 10) show that Echinothrix and Heterocentrotus were the dominant urchins according to the quarter method with "Importance values" of 146 and 116, respectively. Tripneustes and Eucidaris were similar with IV's of 16 and 15, respectively, and Echinostrephus was least important with a value of 8. Importance values determined from the quadrat method were similar, although Heterocentrotus was somewhat less important and Echinothrix somewhat more important. The values are 79 for Heterocentrotus and 164 for Echinothrix followed by 25 for Echinometra, 20 for Eucidaris and 11 for Tripneustes.

Echinostrephus was not detected in the quadrat transect and Echinometra was not counted by the quarter method. The weight/m^2 indicated by the quarter method was 5g for Subset A and 1g for Subset B. The weight indicated by the quadrat method is 130 g $\pm$ 30(SE) with a total of 30 quadrats enumerated. The values are somewhat misleading, however, because of the aggregated nature of the populations. As indicated for forest populations (Cottom and Curtis, 1956) when the populations are aggregated the distance measurements of the quarter method are too long and indicate fewer individuals per unit area than actually are present. Although not documented, all divers agreed that when densities were low there was a good chance that the urchin closest to the block was not always found. The small number of quadrats counted may also lead to an error in estimation.

Area 2. Kaawaloa Cove. The distance measurements of the 6 quarter transects were lumped to form 2-point subsets in each transect. The subsets were then grouped into horizontal sets composed of similar points of all transects (i.e., all subsets with points 1 and 2 of all transects were grouped into a single set, all subsets with points 3 and 4 of all transects were grouped into a single set, etc.). Subsets within each set were tested for homogeneity of means. Subsets were combined according to Duncan's multiple range test at the .05 level. These new subsets were now tested vertically for homogeneity of means and combined where not significantly different. The resulting subsets represented regions of the transects that had similar distance measurements. Seven regions were segregated by this technique. One subset included the major portion of the sampled region and contained 43 points (142 measurements). There was one region with 8 points, one with 4, 3 with 2 points and 1 with only 1 point (Fig. 28). The distance measurements of the major region (Subset E in Fig. 25) were lumped into 1' intervals and the resulting distribution was not significantly different from a Poisson ($X^2_{(3)} = 5.44$, $p > .05$). All other regions had insufficient numbers of measurements with the observed means to permit adequate analysis of randomness of measurement length. The variance-mean ratios of Subsets A and B were 1.8 and 2.5, respectively, indicating aggregation. Mean distance (Table 9) for Subset A was 7.26 $\pm$ 2.32 m which gives a density estimate of .02 + .02 or -.01 animals per meter squared. For Subset B, the mean distance was 2.08 $\pm$ 0.26 m which gives a density estimate of .23 + .07 or -.03 animals per meter squared. For Subset E the distance is 0.64 $\pm$ 0.03 m and the density is 2.45 + .28 or -.23 per meter squared. This indicates a definite decrease in density with depth, a conclusion also reached using the quadrat data (Figs. 29 and 30). All species except <u>Tripneustes</u> decreased in density with increasing depth. Densities were somewhat higher than indicated by the quarter method which gave an average density for depth from about 60 feet to 5 feet. The range indicated from quadrat data, excluding <u>Echinometra</u> to make it comparable to the quarter survey, is 7.54 $\pm$ 1.94 animals per meter squared at a depth of 5 to 10 feet and 0.88 $\pm$ 0.30 per meter squared at 55 to 60 feet. The quarter estimate falls nicely between these two extremes. Whitford's Index of Aggregation (Whitford, 1949) was used to measure degree of aggregation at each depth. This index is simply the ratio of the abundance/frequency where the abundance is the average number of individuals per quadrat of occurrence and frequency is the percentage of quadrats occupied by a given species. Ratios between .025 and .050 indicate a random distribution, higher values suggest aggregation and lower values, regular distribution. For the most abundant urchins, <u>Heterocentrotus</u> and <u>Echinometra</u>, the index

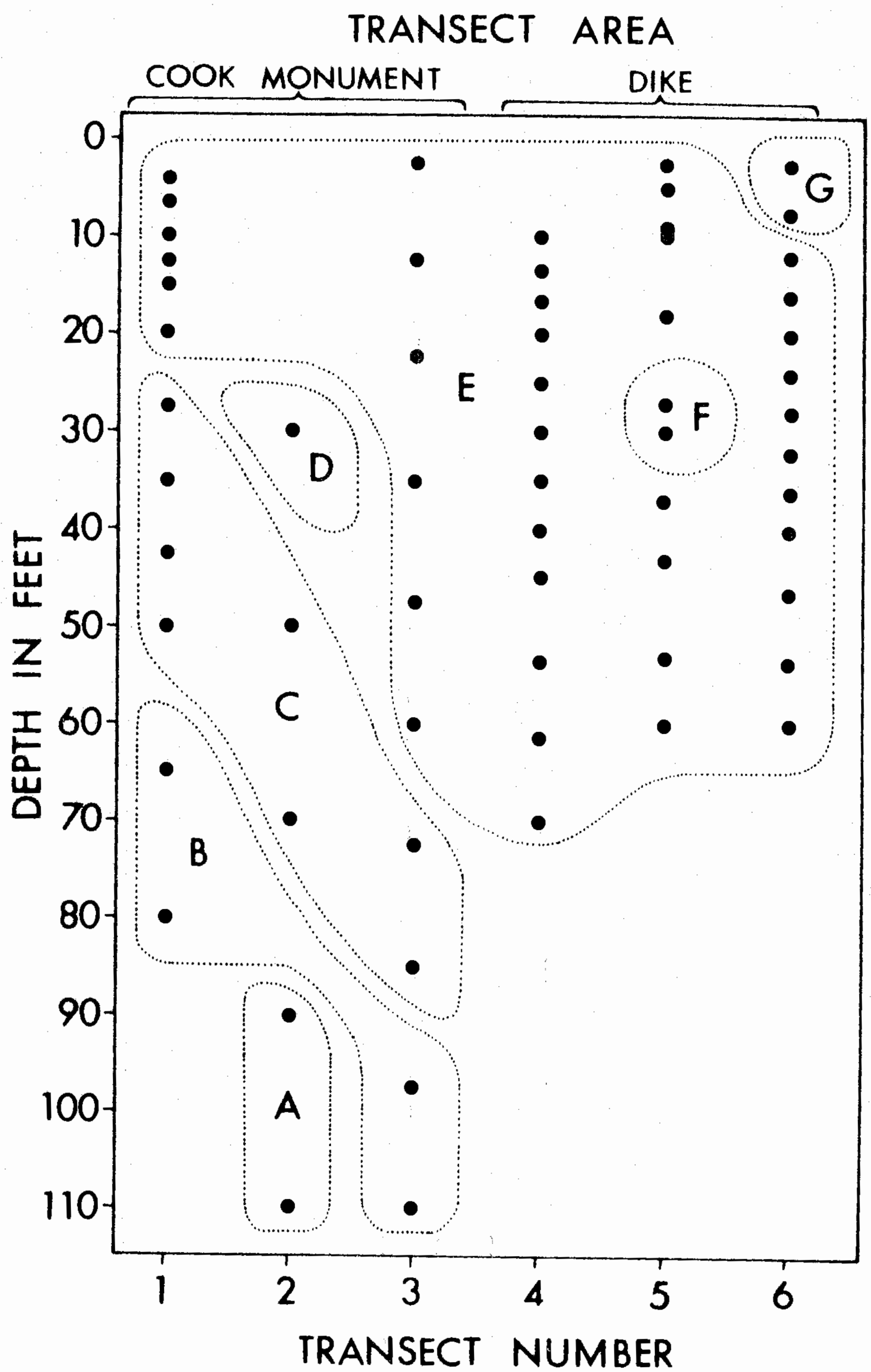


FIGURE 28. Areas of equal urchin density in Kaawaloa Cove determined by the quarter method of sampling and variance analysis. Values for each area are given in Table 9.

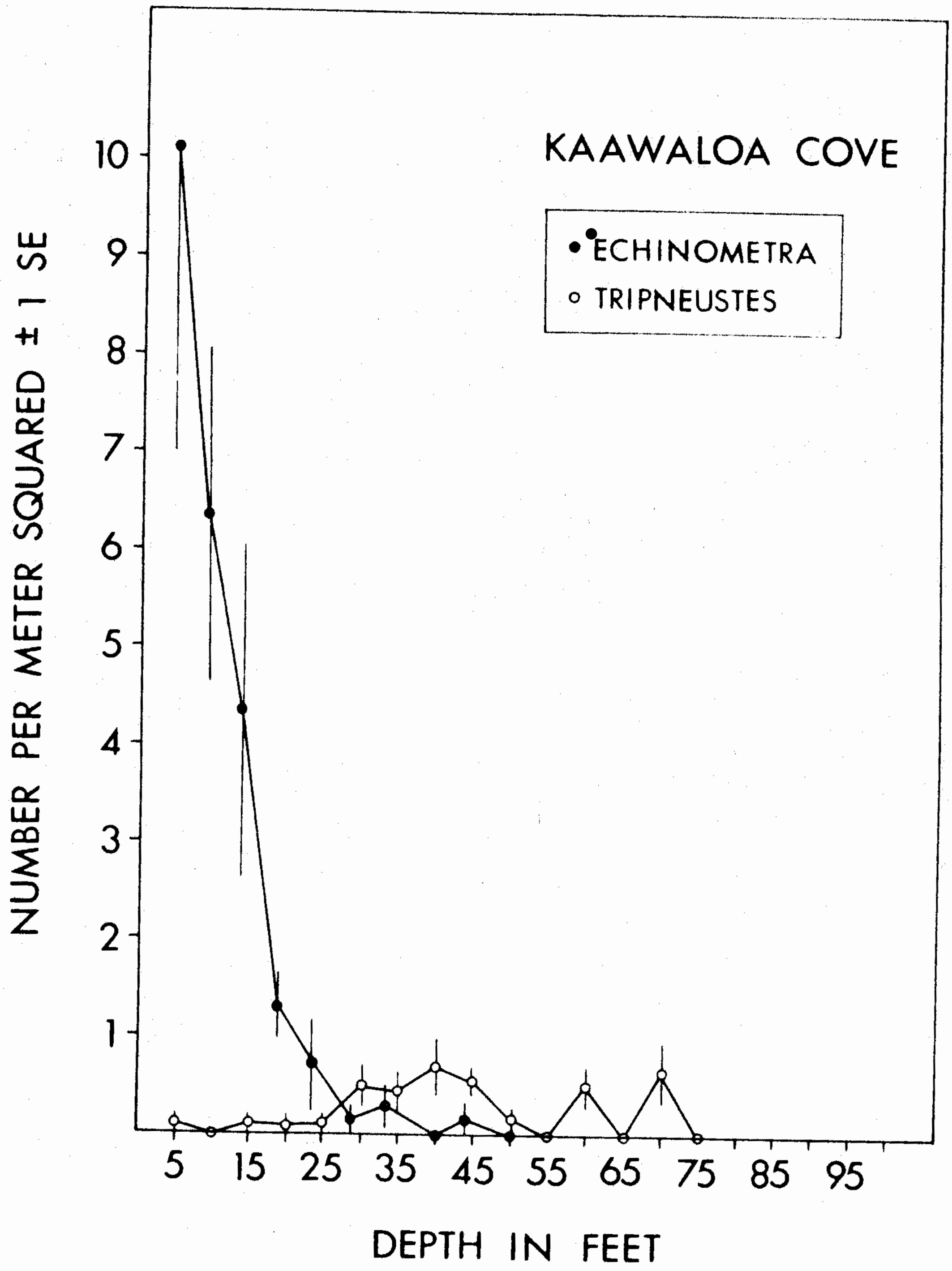


FIGURE 29. Density of the urchins, *Echinometra mathaei* and *Tripneustes gratilla*, as a function of depth.

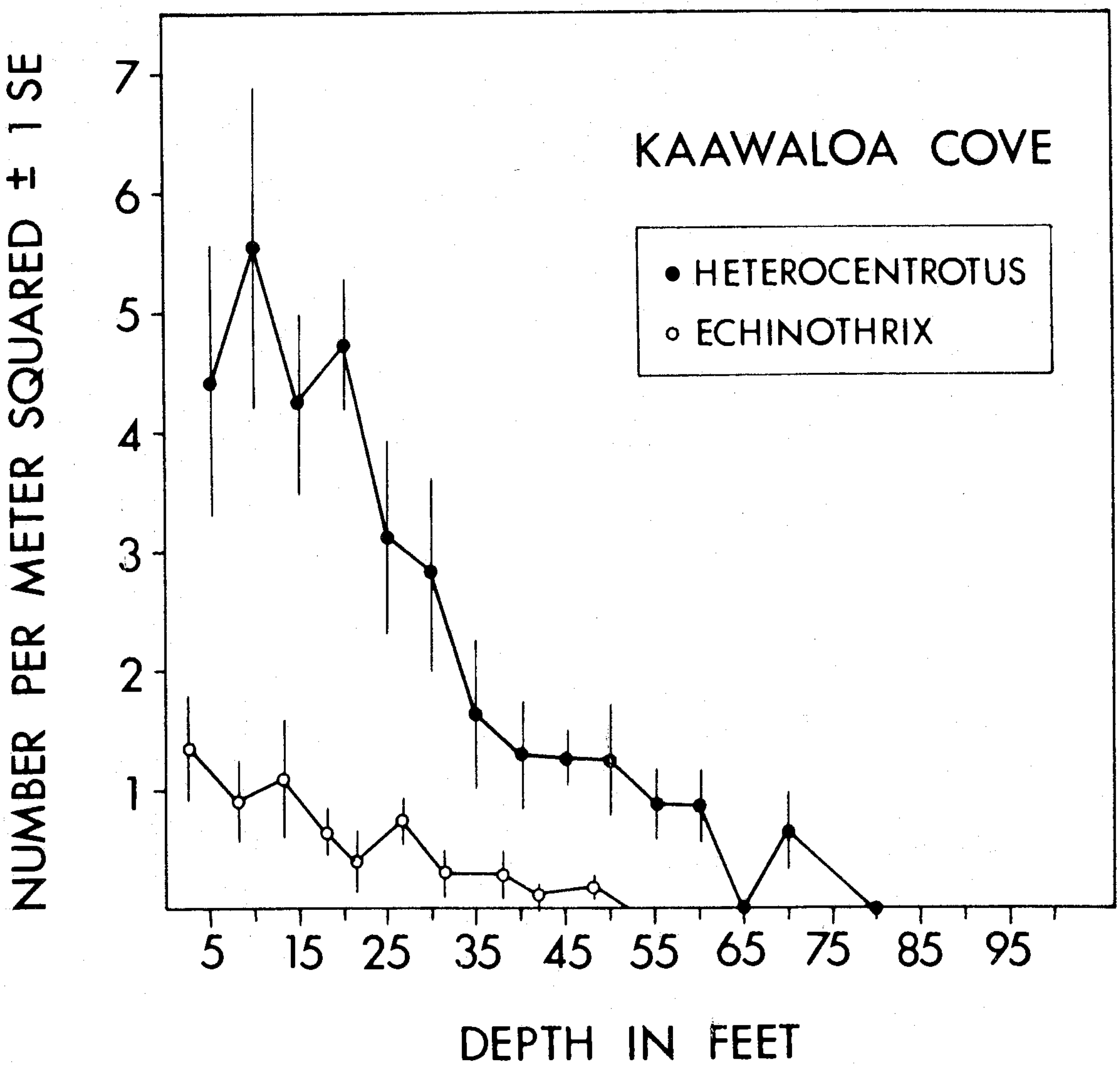


FIGURE 30. Density of the urchin genera, Heterocentrotus and Echinothrix, as a function of depth.

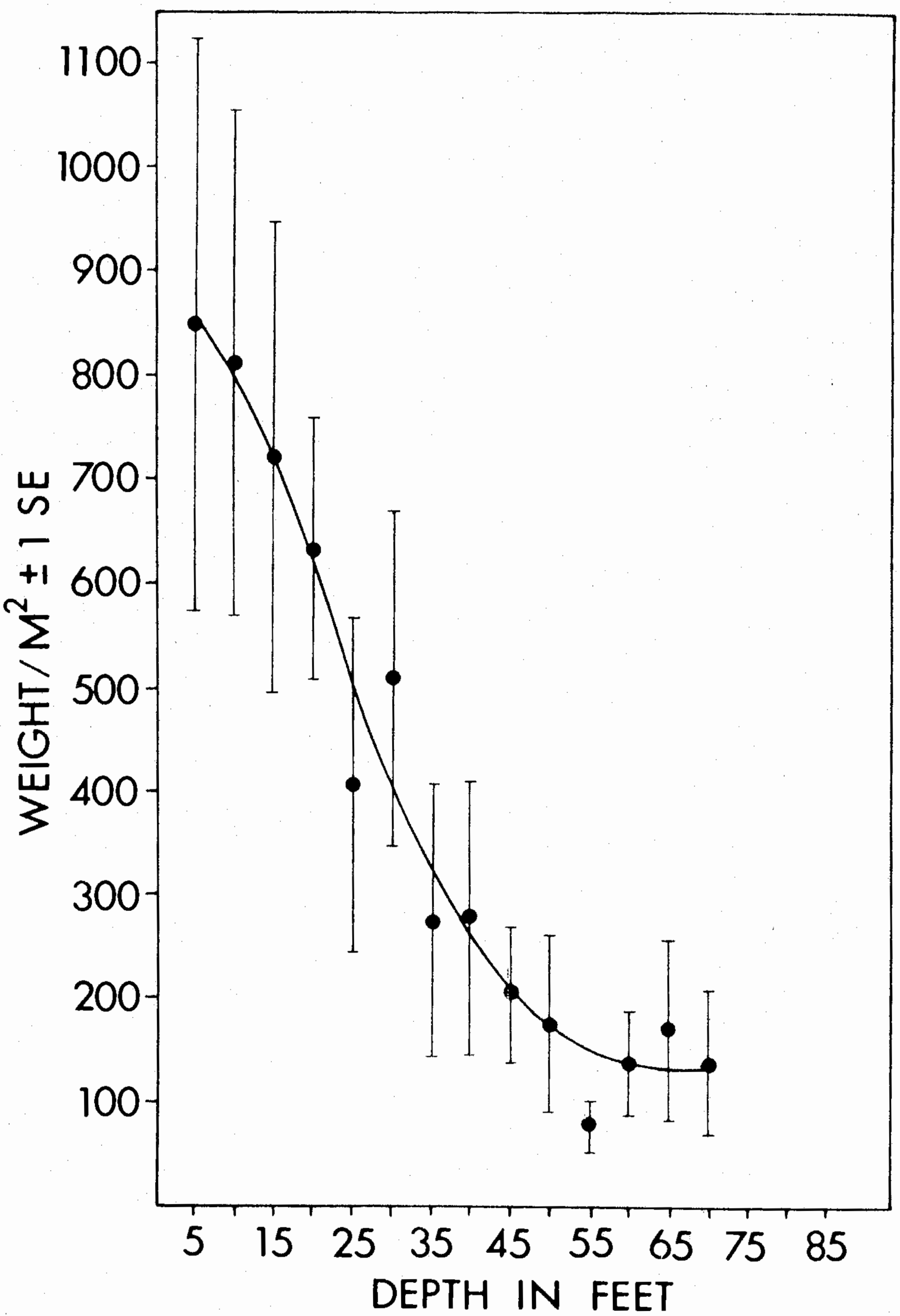


FIGURE 31. Urchin biomass as a function of depth.

decreased with depth. The values near the surface indicated aggregation and bottom values indicated a regular distribution. This is difficult to interpret, however, because the Index is sensitive to variations in density (Curtis & McIntosh, 1950). Values between about 20' and 40' indicated random distribution. This again generally agrees with the quarter data which showed random distribution for Subset E. The two methods disagree in that the low Subsets of the quarter method, B and C, indicated an aggregated distribution of animals.

According to the quadrat data, the only species to increase with depth was Tripneustes. This is also shown by the quarter method where Subsets B and C have greater densities than does Subset E. Relative importance (Table 10) is similar by both methods: Heterocentrotus was the most important for the entire area sampled by quadrats (150) and for Subset E (225) followed by Echinothrix, 63 in Subset E, and Echinometra and Echinothrix both with values of 58 in quadrats. In Subset B, Tripneustes was 131 followed by Echinothrix with 98 and Heterocentrotus with only 47. In Subset C, Tripneustes has an importance value of 123 followed by Heterocentrotus with 104 and Echinothrix with 61. In Subset E, Tripneustes had an importance value of only 4 by the quarter method and an overall value of 26 by the quadrat method. The total weight of urchins was a function of depth (Fig. 30).

Area 3. Napoopoo breakwater. Analysis of variance indicated that the means of the measured distances of the two transects were homogeneous ($F_{(1,69)} = 1.28$, $p > .05$). Distance measurements grouped into 1-foot intervals formed a distribution significantly different from a Poisson ($X^2_{(4)} = 36.5$, $p < .01$). The variance mean ratio was 5.1, indicating aggregation. Mean distance was 2.30 $\pm$ 0.21 m which gives a density estimate of 0.19 + 0.04 or -0.03 animals per meter squared (Table 9). Because the population has an aggregated dispersion pattern, this estimate is too low (Cottom and Curtis, 1956). The nature of the substrate explains the aggregation: coral heads separated by sandy areas. Urchins were not found on sand. Importance values (Table 10) are, however, still valid in describing the composition of the urchin fraction of the community. Heterocentrotus and Echinothrix were similar to Subset E of Kaawaloa Cove and Tripneustes was higher: 199 is the value for Heterocentrotus, 71 for Echinothrix and 30 for Tripneustes.

Area 4. T. Ashihara's cottage. Measured distances for 2-point subsets did not form a homogeneous set for the entire transect ($F_{(8,59)}$ = 4.81, $p < .01$). Two homogeneous sets could be formed using Duncan's multiple range test which separated the transect into its upper 5 points and lower 12 points. Within the lower 12 points, the distribution of distances grouped by 1-foot intervals was significantly different from a Poisson ($X^2_{(2)} = 7.58$, $p < .05$) indicating a non-random distribution of animals. The variance-mean statistic (2.14) showed that the urchins were aggregated. In the upper 5 points, with the observed mean, there were insufficient values to run a X^2 using 1-foot intervals; however, the variance-mean ratio was 2.46 so the animals apparently also were aggregated. The mean distances were 0.92 $\pm$ 0.10 m in the lower subset of the transect and 1.86 $\pm$ 0.24 m in the upper subset. These give density estimates of 1.18 + .30 or -.22 and 0.29 + .43 or -0.14, respectively. Heterocentrotus had the highest importance values in both subsets, 275 in the lower part of the transect and 162 in the upper. Echinothrix was second with 15 in the lower and 118 in the upper. Eucidaris was 9 in the lower and not present in the upper subset, and Tripneustes was 20 in the upper and not present in the lower subset. The distribution of the urchins is interesting when compared with Subset E in Kaawaloa Cove where Eucidaris was present near the surface and not deep and Tripneustes was rare near the surface and more abundant at lower depths.

Area 5. Shallow area at Palemano Point. Sampling was done with a 1-m^2 quadrat in water less than 1-1/2 meters deep. A concentration of Tripneustes was sampled with 30 quadrats. The band of urchins was ca. 8-meters wide and ca. 20 meters long. Mean density within the aggregation was 4.3 per m^2; however, the range was from 0 to 12. Heterocentrotus, Echinothrix and Echinometra were present in the area around the Tripneustes bed but were not abundant. The areas where Tripneustes was present were bare of algae. Algae and coral were present in surrounding areas.

Area 6. Honaunau Bay. The means of the distance measurements of the three transects did not form a homogeneous subset ($F_{(2,129)} = 4.10$, $p < .05$). Duncan's least significant range test indicated that 2 subsets should be formed, one with 23 points (Subset A) the other with 10 (Subset B). Mean distance in Subset A was 0.68 ± 0.05 m and in Subset B it was 0.96 ± 0.10 m. These give density estimates of 2.14 + 0.34 or -0.27 animals per meter squared and 1.08 + 0.17 or -0.09. Distance measurements grouped into 1-foot intervals formed distributions not significantly different from a Poisson in both subsets. Subset A ($X^2_{(3)} = 4.84$, $p > .05$) and Subset B ($X^2_{(2)} = 0.82$, $p > .05$). Importance values of the two subsets were similar although Echinothrix was somewhat more important in Subset B. The values were: for Heterocentrotus 289 in Subset A and 262 in Subset B and Echinothrix 11 in Subset A and 38 in Subset B. The two subsets differed slightly in the method of selecting points. The two transects making up Subset A were set directly perpendicular to the shore and so points were sampled both on the tops of coral mounds and in the valleys between mounds. Subset B was taken by following a valley and did not include points from the tops of mounds. The conclusion is that tops of mound differ from valleys by having more animals and possibly a slightly different species composition. Whether this is the result of some interactions that produced zonation in Kaawaloa Cove is not known.

Area 7. One mile south of Honaunau. The single quadrat-transect at this point was similar to the transect at Napoopoo Light with respect to wave action, exposure, etc. Density without *Echinometra* was estimated to be 0.67 ± 0.24 compared to 0.83 ± 0.19 at the lighthouse, and with *Echinometra* the density was 0.83 ± 0.27 compared to 0.93 ± 0.20 at the lighthouse. The urchins were aggregated as indicated by the variance-mean ratio of 2.0. The most important urchin was *Heterocentrotus* with a value of 131 followed by *Tripneustes* with 108. *Echinothrix* did not appear in the sample and is a major difference between this sample and those at Napoopoo Light where *Echinothrix* was the most important both by the quadrat method and the quarter method.

Discussion

Several general conclusions are warranted from the study of urchins of Kealakekua and Honaunau Bays on the Kona Coast of Hawaii. First, in descending order of importance, the urchins are *Heterocentrotus*, *Echinothrix* and *Echinometra*. This is followed by *Tripneustes* and several minor species: *Eucidaris*, *Diadema*, *Colobocentrotus*, *Chondreocidaris* and *Echinostrephus*. This list is nearly the entire shallow water regular-echinoid fauna of Hawaii. *Lytechinus* and *Pseudoboletia* may be present. This, however, would not make the bays unique for the urchins appear to be generally distributed among the islands (Edmondson, 1946). However, the abundance of *Heterocentrotus* does make the area unique because other than the Kona Coast and a few sites on Maui such as Molikini Reef (J. Maciolek, personal communication), Heterocentrotus is not common. A second conclusion is that urchins form a segment of the shallow water communities that probably receives a large portion of the energy from primary production. This is based on standing crops that may reach nearly 1 kilogram per meter squared. A third general conclusion is that the local distribution patterns and species compositions suggest that limitation of distribution of a given species is complex and not dependent upon a single factor.

The following discussion can conveniently be divided into two parts: the first concerning the probable factors involved in the limitation of the distribution and abundance of urchin species and, secondly, some suggestions of the roles of urchins in community function.

There are at least 5 and possibly 6 factors which must be considered in a discussion of the distribution and abundance of urchins in Kealakekua and Honaunau Bays: depth, substrate, exposure to waves, food, animal behavior and chance. None of these can be definitively assessed with the data presented; however, several reasonable suggestions can be made and the problems for further study can be better defined.

Depth. There was little correlation between assemblage composition and depth. In Kaawaloa Cove, Tripneustes was infrequent near shore in shallow water and showed both a higher density and higher importance value at lower depths. It increased in numbers as other urchins decreased. Off the Ashihara cottage, Tripneustes was rare in the lower part of the transect and more abundant near the shore. At Palemano Point it was the most abundant urchin in 1 meter of water. Eucidaris in Kaawaloa Cove was found only in the quadrats near the surface but is described by Edmondson (1946) as generally being more common at depths of several fathoms. _Chondreocidaris_ was found only in the deepest portions of the transects. Because generally transects were not started below 50-60 feet, it was recorded only from Kaawaloa Cove where some transects were started at 110 feet. Its observed distribution is in accord with that suggested by Edmondson (1946).

There was a striking decrease in the numbers of urchins with increasing depth in Kaawaloa Cove. The reverse, however, was true for the transect off the Ashihara cottage where there were more animals away from shore in deeper water than were present in the shallows. It seems warranted to conclude that depth, _per se_, is unimportant in determining distribution and that in cases where there is a correlation with depth it is necessary to further examine other features of the environment to determine the causes for observed distributions.

Substrate. There appeared to be certain substrate requirements of each species: crevices for _Heterocentrotus_, small ledges or large cavities for _Echinothrix_ and low relief without living coral for _Tripneustes_. Presence of coral, either living or dead, did not appear to be required by _Heterocentrotus_ or _Echinothrix_. In the Ashihara transect, there was living coral away from shore, and near shore the rocks were relatively barren. In Kaawaloa Cove, dead coral increased with depth. The area at Palemano Point where _Tripneustes_ was abundant also lacked living coral. _Heterocentrotus_ was found both on living and dead coral and on lava rocks. The size distribution of _Heterocentrotus_ on the lava tallus by the dike in Kaawaloa Cove was shifted towards large individuals. Whether this is due to a higher growth rate or longer life compared to the coral areas of Kaawaloa Cove is not known.

Exposure. Exposure to the open sea is correlated with numbers of urchins of some species. Generally density decreased from a protected bay to the exposed coast. There was a higher urchin density in all areas of Kealakekua and Honaunau Bays than in transects at Napoopoo Light and one mile south of Honaunau. Species diversity was highest in Kaawaloa Cove but was low in Honaunau Bay so protection from high surf does not insure high urchin diversity. Certain species were surf sensitive. Colobocentrotus was not present in Kaawaloa Cove but was common by the lighthouse and was observed at the top of the transect at the Ashihara cottage. Echinometra oblonga was not present in Kaawaloa Cove but appeared in slightly more exposed conditions such as the Ashihara transect and at the tops of the transects in Honaunau Bay. Echinostrephus was recorded only in Kealakekua Bay and was more important in samples from the lighthouse. A single specimen was recorded in Kaawaloa Cove. Heterocentrotus had higher importance values in protected regions and also higher densities. Echinothrix appeared to be less sensitive to wave exposure than did Heterocentrotus and so its importance values tended to increase even though its densities decreased. Tripneustes shows no consistant pattern with respect to exposure. At Napoopoo Light it formed a relatively unimportant fraction of the urchins with an importance value of 20 by the quarter method and 11 in the quadrat transect. One mile south of Honaunau, Tripneustes was the second most important animal with an importance value of 108. In Kaawaloa Cove in Subset B, which is below 50', Tripneustes was the most important with a value of 130. It was most dense in the highly protected area at Palemano Point. If there is a pattern it suggests that Tripneustes can survive under a wide range of surf conditions but does best in protected areas.

Food. In Kaawaloa Cove, the decrease in urchin numbers with increasing depth does correlate with decreasing light and so presumably with primary productivity. Unlike _Strongylocentrotus_ (Ebert, 1969) in which biomass but not numbers appeared to be food limited, both numbers and biomass of urchins in Kaawaloa Cove correlate with decreasing primary production. Whether food was actually limiting was, of course, not determined by this study and the importance of the substrate as indicated in that section may be of primary importance.

Behavior. Behavior during two stages of the life cycle would be important: larval settling and movements of the adults. There are indications that urchins tend to settle where adults live (Moore _et al_., 1963; Ebert, 1969). The larvae also obviously have the ability to settle in areas not occupied by adults and so colonize new areas. As adults, _Echinus_ is known to make seasonal migrations (Elmhirst, 1922; Stott, 1931) and _Strongylocentrotus purpuratus_, _S. franciscanus_ (Leighton, 1963, _in_ North, 1963) and _Paracentrotus_ (Kitching and Ebling, 1961) are known to move in response to low food. In Kaawaloa Cove, low production in deep water may be a stimulus which causes adults to migrate towards the surface. Adult movement would be important only for those species that do not live in cavities of their own construction. It is unlikely that the distribution of _Echinometra_ or _Echinostrephus_ is determined by adult behavior.

Chance. Certain features of the distribution of urchins in this study appear not to be associated with physical or biological factors. At Napoopoo Light, _Echinothrix_ was calculated to have an importance value of 143 by the quarter method and 164 by the quadrat method. It did not appear in the transect one mile south of Honaunau. _Tripneustes_ was also different between these two stations as indicated in the section on exposure, being high south of Honaunau and low by the lighthouse. Finally, *Heterocentrotus* is highly important in most of the sites examined along the Kona Coast yet is generally uncommon in other areas along the Hawaiian Island chain. Whether *Heterocentrotus* has always been rare in other areas is not known for certain. Edmondson (1946) lists *Tripneustes* and *Echinothrix* as common forms and says that *Heterocentrotus* "frequents the outer border of the reef platform, but young specimens are sometimes seen near the shore." This applies mainly to Oahu. The impression is given by Edmondson that *Heterocentrotus* certainly has not been a dominant element of the echinoid fauna for the past 70 years, if it ever was. Even though *Heterocentrotus* is collected to make wind chimes for tourists and Oahu has a much higher human population, there are areas both on Oahu and other islands that are at least as free of human intervention as is the Kona Coast of Hawaii. *Heterocentrotus* is even present in Kailua Bay on the Kona Coast which receives substantial human waste pollution. The environment seems to be no different along the Kona Coast than it is in many other areas of Hawaii. A definite possibility for explaining this distribution is that chance has played a very important role on a small scale in determining local distributions of such urchins as *Echinothrix* and *Tripneustes* and on a larger scale in the establishment of the larger populations of *Heterocentrotus* along the Kona Coast.

Function of urchins within the community

In order to properly evaluate the role of urchins in the communities along the Kona Coast, it would be necessary to have information available on growth, recruitment, mortality, feeding and respiratory rates and a further analysis of the biomass in terms of caloric content rather than simply wet-weight. However, even with such limitations, it is still possible to make a reasonable estimate of biomass turnover and of possible rates of recovery should the community be damaged by collecting, pollution or natural disaster. The highest secondary productivity in natural waters reported by Odum (1959) was 39 g/m^2-year for German fish ponds (Viosca, 1935). At this rate it would require between 5 and 6 years to accumulate the biomass of 200-300 g/m^2 estimated as an average in Kaawaloa Cove and Honaunau Bay. Considering that urchins still must share energy from primary production with the rest of the community and that urchin populations will experience an energy loss due to mortality, the population turnover rates most certainly exceed 5 years and quite likely are closer to 10. Such a period of time is important in evaluating the ability of a community to repair itself. Community damage and unbalance of sea urchin populations have been reported by North *et al*. (1963) who showed that the purple sea urchin *Strongylocentrotus purpuratus* increased in the area around San Diego, California, apparently as a result of pollution (Leighton *et al*., 1966). The pattern apparently was that first pollutants killed the kelp *Macorcyctis* and then the urchin populations "exploded" and prevented the reestablishment of the kelp. I have discussed the regulation of intertidal populations of *Strongylocentrotus* in Sunset Bay, Oregon (Ebert, 1969), and concluded that numbers of individuals appeared to be regulated by "suitable places in which to live" (Andrewartha, 1961), but that biomass was regulated by available food. The distributions may be similar with inter-relations of substrate and food in determining distribution and abundance under a given exposure condition. A further modification found in the sub-littoral populations examined would be the ability of adult urchins to modify their distributional pattern in response to food, substrate or exposure. This obviously is highly speculative and is included mainly to pose a direction for further work.

Predictions of the results of human activities must naturally be very tentative; however, a number of most probable results can be suggested. First, anything that would tend to eliminate the living coral would probably change the species composition of Kaawaloa Cove or Honaunau. The most likely change would be reduction of Heterocentrotus and a possible increase of Tripneustes. With the associated decrease in relief of the bottom, Echinothrix would also be decreased. Sewage treatment plants would increase turbidity and, through light attenuation, would decrease productivity with depth. This would cause a sharper zonation of urchins with fewer at lower depths. The net result would be an overall decrease in urchin biomass. Because it presently is not known whether the abundance of Heterocentrotus on the Kona Coast represents part of a "climatic climax" or was determined by chance, the recovery of a bay such as Kealakekua after a disaster is difficult to predict. If the area is a climatic climax it would return to its original state. On the other hand, if the species composition was established by chance, then severe damage would not necessarily be reparable. From the data presented in this study, it appears likely that chance may be important.

Chapter 10

CRUSTACEA

The only larger crustacean seen in numbers was the "cleaning shrimp," _Stenopus hispidus_. Although it seems likely that many smaller decapods live among the deep interstices of the coral, it seems equally likely that such crustaceans would occur among the coral rubble bordering the deep sand. Several coral fragments were overturned without noting such crustacea.

The number of lobsters (_Panulirus japonicus_) observed in Kealakekua Bay was thought disproportionately few considering the abundant cover. It was concluded they are scant here.

Kona crabs (_Ranina serrata_) were also rarely seen, but are thought by some to be abundant in Kealakekua Bay. They were noted in the sandy bottom on two Fish and Game transects in the bay, and local residents engage in crab trapping. The red pebblecrab (_Etisus splendidus_) was also infrequently reported.

Kona crabs live in sandy areas not frequented by fish. They are dawn feeders, remaining burrowed in the sand during daylight hours, and hence would be easily missed by the surveying SCUBA divers working, as they did during this survey, only by day.

Chapter 11

FISH

(Division of Fish and Game's fish survey report)

Introduction

This is a summary of the Division of Fish and Game's fish survey activities at Kealakekua Bay and Honaunau Bay, Kona, Hawaii. During the period from June through December, 1968, three fish surveys were made to the area in June, August and October. (For exact dates and activities during these surveys see Quarterly survey reports by Division of Fish and Game, State of Hawaii.)

In June, a preliminary surface survey was made at Kealakekua Bay and Honaunau Bay to select sites for our permanent fish survey stations. Seven stations were selected, five in Kealakekua Bay and two in Honaunau Bay. The locations and directions of these stations are described in charts submitted with the Quarterly survey report.

At each station, we laid a permanent stainless steel underwater transect line 250 yards long with tile blocks spaced 25 yards apart to keep the line in place. The transect line at station no. 3 (Kealakekua Bay) was not laid on the first survey (June), but established on the second survey (August). The line at station no. 2 (Kealakekua Bay) was of nylon and changed to stainless steel on the second survey. The transect line at station no. 5 was 200 yards long and extended to 250 yards in August. The landmarks used to locate each transect line were presented in the first Quarter survey report.

To survey the fishes at each station, we used two divers swimming along each side of the transect line, identifying, counting and estimating size of fish within 20 feet of the line. For the distance of 250 yards or 750 feet, the 40-foot-wide strip (20 feet on each side) equalled 30,000 sq. feet or 0.7 of an acre. The fish counts are later converted to total pounds of each species with length-weight constants and expressed in pounds of fish per acre.

Results

The following are summaries of number of fishes counted, species composition and pounds of fishes per acre.

Number of Fishes Counted

The number of fish counted at each station ranged from 533 to 2,366 with an over-all average of 1,152 fish counted per station. The largest average number of fishes (1,837) was counted on station no. 7 in Honaunau Bay and the lowest average counts occurred on stations nos. 4 and 5 in Kealakekua Bay. Counts of fish on the stations are presented in Table 11.

TABLE 11. Number of fish counted at each station on each survey.

	Kealakekua Bay					Honaunau Bay		
Survey	Station 1	2	3*	4	5	6	7	
June	1,073	1,133	-	561	616	925	2,366	
Aug.	918	1,064	583	716	533	1,623	975	
Oct.	912	1,937	1,356	673	792	2,106	2,170	
TOTAL	2,903	4,134	1,939	1,950	1,941	4,654	5,511	
MEAN	968	1,378	970	650	647	1,551	1,837	1,152

* Station no. 3 established in August.

Species Composition

One hundred and twenty-one different species of fishes were observed in Kealakekua Bay and Honaunau Bay on the three surveys (Table 16). Of this, 110 species were found in Kealakekua Bay and 98 species were found in Honaunau Bay.

Of the fishes in Kealakekua Bay, 32 species were found on all five stations. In Honaunau Bay, 59 of the species were found on both of the two stations. Among the different species in Kealakekua and Honaunau Bays, there were 87 species that occurred on the surveys at all stations and there were 13 species that were present in all stations during every survey. These most common species are given in Table 12.

TABLE 12. Fish species observed on all stations on every survey in Kealakekua Bay and Honaunau Bay.

	Scientific Name	Common Name
1.	Centropyge potteri	Potter's angel
2.	Chaetodon ornatissimus	Orange stripe butterfly
3.	C. multicinctus	
4.	Chromis leucurus	White-tail damsel
5.	Ctenochaetus strigosus	Kole
6.	Forcipiger longirostris	Long-nose butterfly
7.	Naso lituratus	Kala
8.	Parupeneus multifasciatus	Moano
9.	Pomocentrus jenkinsi	Yellow eye damsel
10.	Scarus dubius	Uhu
11.	Zanclus canescens	Kihikihi
12.	Zebrasoma flavescens	Yellow tang
13.	Thalassoma duperreyi	Hinalea

The number of species observed at each station ranged from 37 to 58 with an average of 48 species per station. The number of species observed on stations and surveys are presented in Table 13.

TABLE 13. Number of fish species observed on station during surveys.

	Kealakekua Bay					Honaunau Bay	
Survey	Station 1	2	3*	4	5	6	7
June	47	44	-	41	38	48	47
Aug.	50	52	39	43	34	57	49
Oct.	49	57	63	43	40	69	49
MEAN	49	51	51	42	37	58	48

* Station no. 3 established in August.

Pounds Per Acre

The weight in pounds per acre of the standing crop of fishes in Kealakekua and Honaunau Bays are presented in Table 14.

TABLE 14. Pounds per acre of fishes in Kealakekua Bay and Honaunau Bay, Hawaii.

	Kealakekua Pay					Honaunau Pay	
Survey	Station 1	2	3	4	5	6	7
June	151	163	-	175	111	276	324
Aug.	267	204	102	102	58	274	138
Oct.	283	385	669	107	163	603	306
MEAN	234	251	-	128	111	384	256

* Station no. 3 established in August.

The standing crop of fishes ranged from 58 to 603 pounds per acre with an average of 227 pounds per acre per station. The stations in Kealakekua Bay had an average of 210 pounds of fish per acre and in Honaunau Bay there was an average of 320 pounds of fish per acre. The lower average pounds per acre in Kealakekua Bay was due to stations nos. 4 and 5 which ran across sandy bottoms with very few fish. The lesser number of fishes counted on stations nos. 4 and 5 was shown previously (Table 11).

A determination was also made of the relative ranking by greatest pounds per acre of the fishes in Kealakekua and Honaunau Bays (Table 15) and the occurrence of these species among the seven stations. Of the 34 species involved in this comparison, the yellow tang (Zebrasoma flavescens) and kole (Ctenochaetus strigosus) occurred on all seven stations and were the commonest and most numerous species in both bays. It was previously mentioned that these two species were present at every station and on every survey.

Finally, it should be noted that in Kealakekua and Honaunau Bays, there are "spots" away from the permanent stations that contained species that were not seen along the transect lines. For example, it was reported that Kona crabs (Ranina serrata) are present in the sandy bottom on stations 4 and 5. There is also reported to be a "moi hole" along the surf zone near Palemano Point in Kealakekua Bay. During the process of locating the transect lines on station no. 4, we have also seen large rays (both Aetobatus narinari and Manta birostris).

TABLE 15. Frequency of occurrence of the top ten fish species ranked by pounds per acre.

Species	Average Lbs./Acre on Stations	Kealakekua Bay				Honaunau Bay	
	1	2	3	4	5	6	7
Zebrasoma flavescens	15	22	13	13	9	35	22
Ctenochaetus strigosus	15	18	19	9	14	30	14
Scarus perspicillatus	51	18	14	9	11	12	
Naso lituratus	23	15	10	5	13	36	
Scarops jordani	30	30		23	24		
Acanthurus leucopareius	9	25	17			13	
Scarus dubius	15			13	8		
Acanthurus olivaceus	25	11		8			
A. achilles		22	10				
A. dussumieri					4		14
Dascyllus albisella				8			19
Melichthys buniva		15					15
Scarus sordidus	25						
Acanthurus xanthopterus			13				
A. guttatus						28	
A. nigrosis		16					
Naso brevirostris	18						
N. unicornis						86	
N. hexacanthus							11
Iso hawaiiensis						29	
Thalassoma duperreyi			12				
Chromis verater					10		
C. leucurus					4		
Chanos chanos						41	
Zanclus canescens						11	
Chaetodon ornatissimus							18
Mulloidichthys samoensis							25
M. auriflamma							9
Myripristis berndti							14
Carangoides ajax			385				
Polydactylus sexfilis			36				
Aprion virescens				23			
Gymnothorax flavimarginatus				6			
Cheilinus rhodochrons					4		

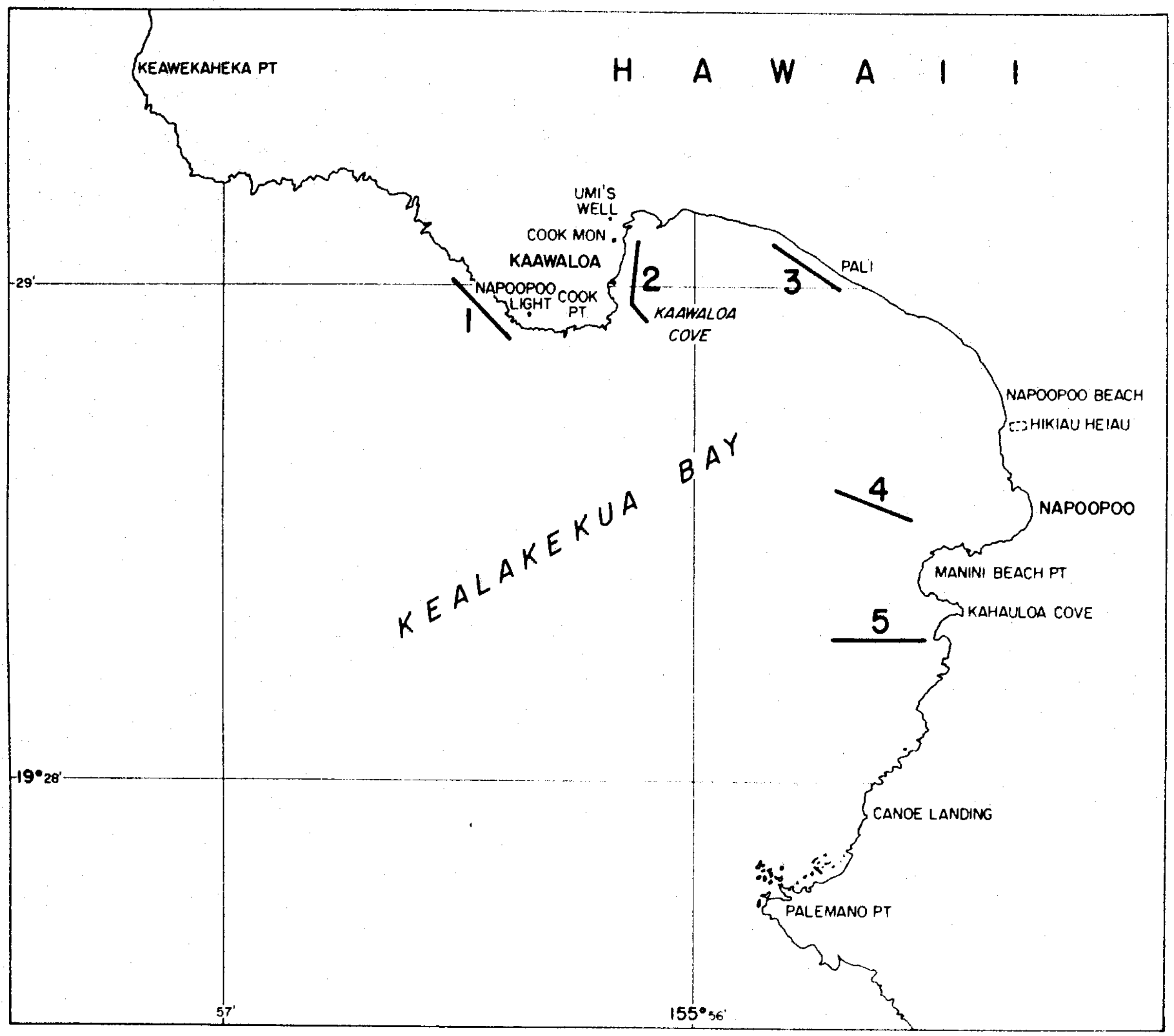


FIGURE 32. Fish transect lines, Kealakekua Bay. Lines 1 through 5 are indicated.

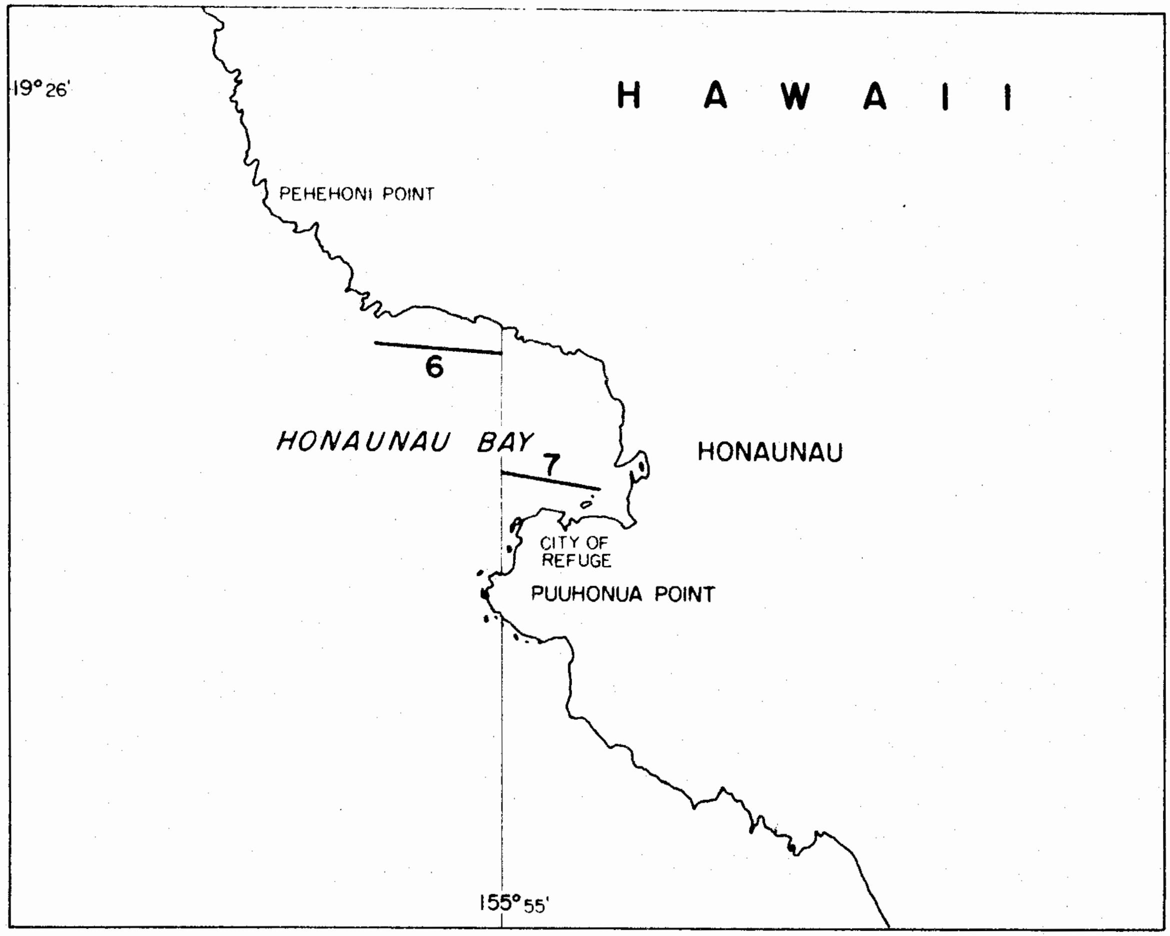


FIGURE 33. Fish transect lines, Honaunau Bay. Lines 6 and 7 are indicated.

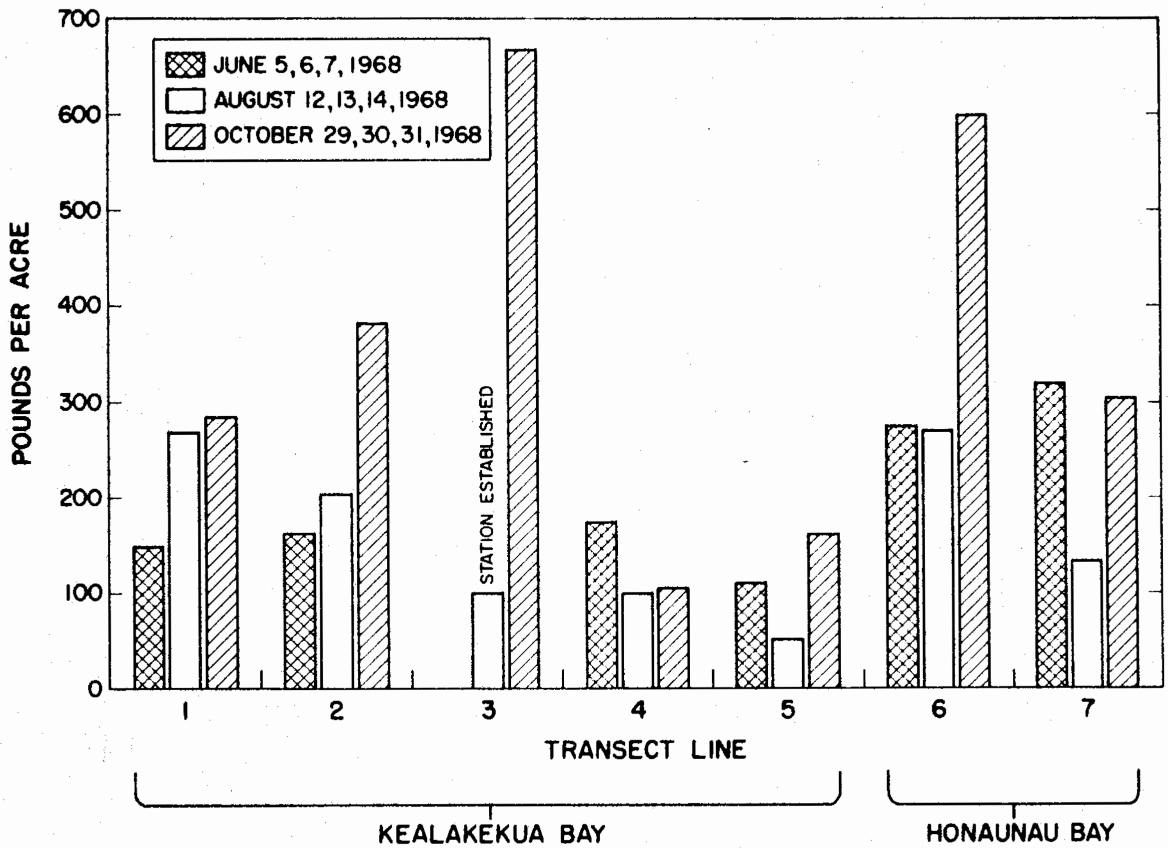


FIGURE 34. Comparison of pounds per acre of fishes observed during three surveys at the seven permanent transect stations in Kealakekua Bay and Honaunau Bay.

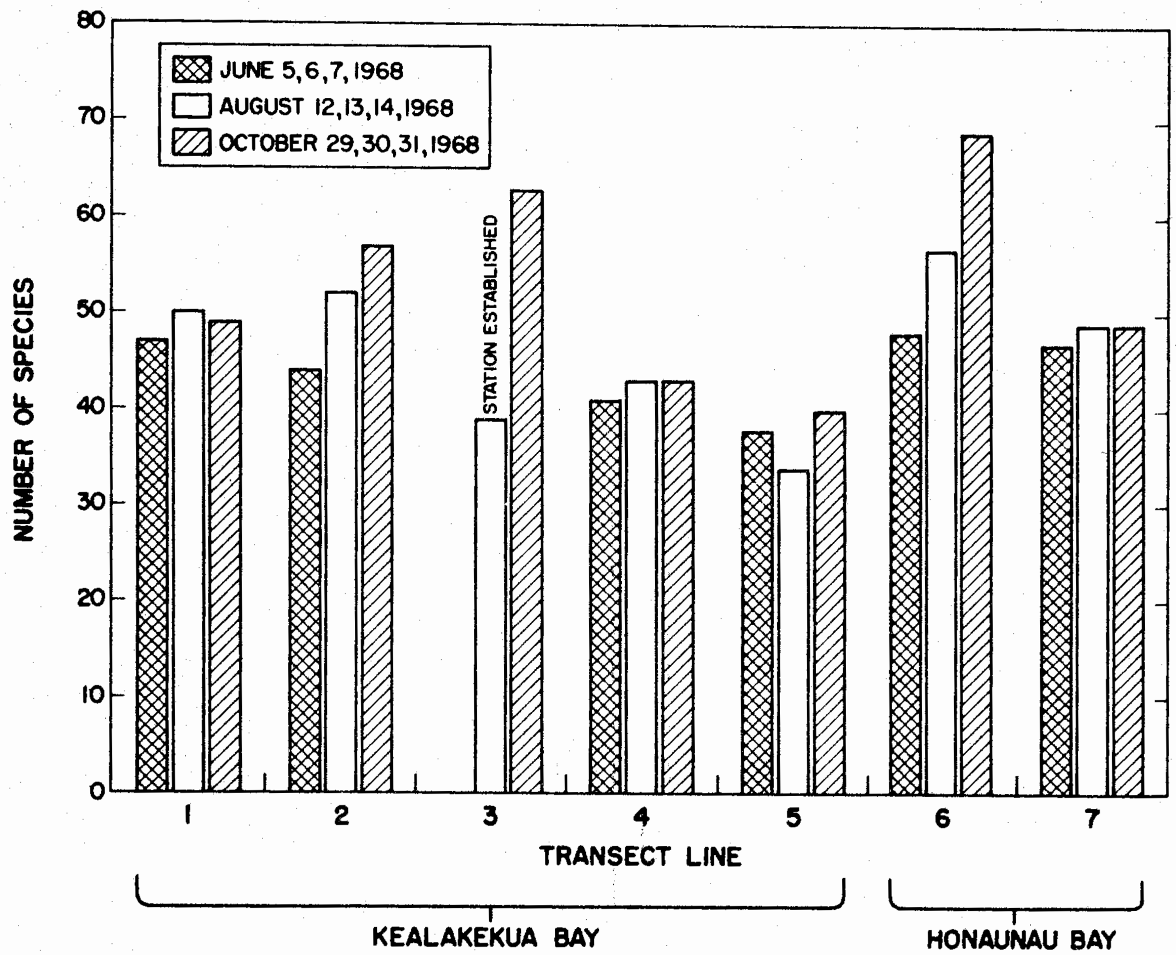


FIGURE 35. Comparison of number of species of fishes observed during three surveys at the seven permanent transect stations in Kealakekua Bay and Honaunau Bay.

TABLE 16. Fishes observed in Kealakekua Bay and Honaunau Bay, June through October, 1968.

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre Kealakekua Line No: 1	2	3	4	5	Honaunau 6	7
Lizard fish	Synodous variegatus				.71		.06	.80
Eel - Puhi paka	Gymnothorax flavimarginatus				6.10			1.81
	G. steindachneri		.76					
Cornet fish	Fistularia petimba	.98	.40	.17				.05
Trumpet fish	Aulotsomus chinensis	.46	1.19	.53	.29	.04	.50	3.88
Squirrel fish	Holocentrus ensifer				.45	.24		
Alaihi	H. xantherythrus			.03	.11		.25	.06
	H. diadema	.05						
	H. sammara		.37		.73			
	Holotrachys lima							3.57
U'u	Myripristis berndti	.84	1.40	.99	3.33	2.89	4.44	14.28
	M. multiradiatus						.16	
Introduced Grouper-Roi	Cephalopholis argus	.48					.73	
Aweoweo	Priacanthus cruentatus							.84
Upapalu	Apogon snyderi			.18	.40		.06	.35

TABLE 16. (continued)

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre						
		Kealakekua					Honaunau	
	Line No.	1	2	3	4	5	6	7
Kahala	Seriola dumerilii		2.94				1.51	
White ulua	Carangoides ajax			385.39				
Omilu	Caranx melampygus		5.42				4.65	
Lae	Scomberoides sancti-petri		4.83					
Uku	Aprion virescens				22.50		.87	
Gurutsu	Aphareus furcatus	.98	1.51			.30	.87	
Spot weke	Mulloidichthys samoensis		.36	7.39	2.38	.71	.24	25.38
Red weke	M. auriflamma		.07	.57	.08		.86	8.87
Malu	Parupeneus pleurostigma	.26	3.13	.20	.67		.08	.14
Kumu	P. porphyreus			.72				1.93
Manu	P. bifasciatus	4.23	4.07		.34	.16	2.31	.71
Moano	P. multifasciatus	1.61	2.29	2.30	1.33	1.49	5.25	2.34
Moana kea	P. chryserydros	.97	3.10	1.25	.38		.37	
Mu	Monotaxis grandoculis	3.33	.28		1.18	1.41	3.52	.56
Black-white angel	Holacanthus arcuatus	.10			.10			.41
Potter's angel	Centropyge potteri	.78	.70	.88	.69	1.81	1.56	3.25
Longnose butterfly	Forcipiger longirostris	1.44	1.74	1.12	.55	.72	3.73	2.60

TABLE 16. (continued)

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre Kealakekua Line No. 1	2	3	4	5	Honaunau 6	7
Blue stripe	Chaetodon fremblii	.26	.66	1.64	.30	.11	1.23	.62
Corallicola	C. corallicola				.31			
Cross striped	C. auriga		2.30		.27			
Orange striped	C. ornatissimus	3.55	4.96	4.65	2.13	2.12	6.01	18.10
Puka	Chaetodon miliaris			.09				.29
	C. trifasciatus	.38	.19	.64				.09
	C. multicinctus	2.00	5.10	3.53	2.27	1.69	4.02	4.45
	C. unimaculatus	.08	.55	.15	.09	1.21		
	C. lunula	1.15	2.33	3.54	.20	.42	1.04	.74
	C. quadrimaculatus	.78	.87	.62		.18	1.40	
	Hemitaurichthys zoster		.18	.18			.09	
Pilikoa	Paracirrhites cinctus	60	.17	.31		.23	.58	
	P. forsteri	1.56	2.47	1.63	1.02	.30	.35	.36
	P. arcatus	.51	.14	.20			.55	.07
Poo-paa	Cirrhitus alternatus	.60	1.19	.50			.25	

TABLE 16. (continued)

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre Kealakekua 1	2	3	4	5	Honaunau 6	7
	Line No.	1	2	3	4	5	6	7
Maomao	Abudefduf abdominalis		5.12	.74	2.28	2.03	3.25	
Kupipi	A. sordidus			.79			.12	
	A. imparipennis	.14						
	Pomacentrus jenkinsi	1.79	5.79	3.75	.31	.68	4.91	2.12
Aloiloi	Dascyllus albisella		.11		7.97		6.56	18.92
	Chromis dimidiatus		.09	.05			.01	
White tail	C. leucurus	.46	2.42	.60	1.80	4.36	5.69	2.50
Black damsel	Chromis verater	2.72	1.44		3.29	9.70	6.94	6.69
Blue damsel	C. ovalis	3.16	.70		.20	.19	3.06	2.79
	C. vanderbilti		.06					
A'awa	Bodianus bilunulatus				.85			
Hinalea lauwili	Thalassoma duperreyi	4.69	8.74	12.21	2.77	2.28	6.94	6.69
Hinalea luahine	T. ballieui	.19	.47		.40	.28	1.67	1.34
	T. lutecens					.06		
	T. fuscum	.96						
	T. umbrostigma			.28				

TABLE 16. (continued)

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre Kealakekua Line No. 1	2	3	4	5	Honaunau 6	7
Birdfish (hinalea i'iwi)	Gomphosus varius	.89	1.81	.64	.24	.18	.57	.20
Hinalea lolo	Coris gaimardi	.67	.80	.31	1.59	1.16	.88	2.42
Hilu	C. flavovittata					.01		.27
Opule	Anampses cuvieri	.12	.92		.22		.30	.36
	A. rubrocaudatus						.02	.11
Labroides	Labroides phthirophagus	.04	.07	.12	.05	.04	.07	.08
	Novaculichthys taeniourus	.24	.71	.24	.32	.24	.14	.14
	Pseudocheilinus octotaenia					.06	.05	.05
Ohua	Stethojulis albovittata	.05				.10	.59	.10
Omaka	S. axillaris	.17	.19	1.11	.19	.52	.04	.10
Poou	Cheilinus rhodochorous	2.51	.10		.23	3.67	.30	1.55
	C. bimaculatus							1.05
Uhu	Scarus dubius	14.92	9.15	9.66	12.98	7.69	4.77	6.80
Band snout	S. perspicillatus	50.89	17.59	13.74	8.71	11.16	11.97	8.10
	S. sordidus	25.40			1.88	2.43	3.90	2.79

TABLE 16. (continued)

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre Kealakekua					Honaunau	
	Line No.	1	2	3	4	5	6	7
	Scarops jordani	30.11	30.11		23.13	23.52	1.88	
Sleeping uhu	Calotomus sandvicensis	8.13	1.32		.60		.25	1.20
Kihikihi	Zanclus canescens	3.77	4.33	3.33	1.09	2.80	10.79	3.37
Surf maiko	Acanthurus guttatus		.23				28.41	
Pakuikui	A. achilles	4.28	22.05	9.84	.16	.68	1.17	.44
White-banded maiko	A. leucopareius	9.33	24.63	17.23	.49		12.53	.61
Maiko	A. nigrofuscus	2.61	2.11	4.71	1.00	1.15	1.98	1.13
	A. nigroris	2.23	15.64	2.40	.27	1.27	2.48	2.62
Naenae	A. olivaceus	24.85	11.44	2.26	8.04	2.45	1.20	4.23
Manini	A. sandvicensis	.12	5.27	1.52			1.96	2.44
Palani	Acanthurus dussumieri	4.44	4.55	5.64	1.09	3.81	5.16	13.82
Pualu	A. xanthopterus		.30	13.05	.37	.19	2.93	.22
	A. mata	1.40		4.22			3.05	3.00
	A. thompsonii	1.61	.82		.36			.02
Kole	Ctenochaetus strigosus	14.89	17.73	19.48	8.62	13.93	30.08	14.44

TABLE 16. (continued)

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre Kealakekua Line No. 1	2	3	4	5	Honaunau 6	7
Hawaiian kole	C. hawaiiensis		.30	.09	.17	.10	.23	.26
Yellow manini	Zebrasoma flavescens	15.18	21.97	13.11	13.02	8.86	35.36	22.88
Sailfin tang	Z. veliferum		8.83		.48	.16	1.24	.48
Kala	Naso hexacanthus						8.62	11.38
Horned kala	N. brevirostris	17.78		1.46				
Kala	N. unicornis	5.84	6.33				86.35	
	N. lituratus	22.98	15.02	10.30	4.71	12.62	35.89	5.44
Humuhumu	Balistes bursa	3.52	.53	1.12	1.10	2.27	1.67	3.97
Humuhumi-mimi	B. capistratus					.74	.31	
Humuhumu-uli	Melichthys vidua	.10		1.04	1.04	.40	2.76	1.71
Humuhumu-ele'ele	M. buniva	4.46	15.29	.81		.51	1.91	14.90
	Xanthichthys ringens	1.63		.16				2.60
Humuhumunukunukuapuaa	Rhinecanthus aculeatus		.31					
Humuhumunukunukuapuaa	R. rectangulus		1.58	1.11				
Ohua	Amanses sandwichiensis		1.38					

TABLE 16. (continued)

COMMON NAME	SCIENTIFIC NAME	Average Pounds/Acre Kealakekua Line No. 1	2	3	4	5	Honaunau 6	7
Oili uwiwi	Pervagor spilosoma	.41	.16	.50	.27	.09	.43	.11
Moa	Ostracion lentiginosus	X	X	X			X	X
Smooth puffer	Arothron hispidus		2.33				2.30	
Banded puffer	Canthigaster cinctus				.19			
Spotted puffer	C. jactator	.11	.18	.09				.07
Sharp nose puffer	C. rivulatus							.33
Blenny	Blenniidae (unidentified)		X					X
	Cirripectus obscurus			X			X	
	Iso hawaiiensis						29.04	
Aawa	Chanos chanos						40.65	
Moi	Polydactylus sexfilis			36.30				
Lion fish	Pterois sphex			.07				
Lobster	Panulirus penicillatus		7.26					
Fairy shrimp	Stenopus hispidus							X

X = observed but weight not determined

Chapter 12

OTHER MARINE VERTEBRATES

Sharks

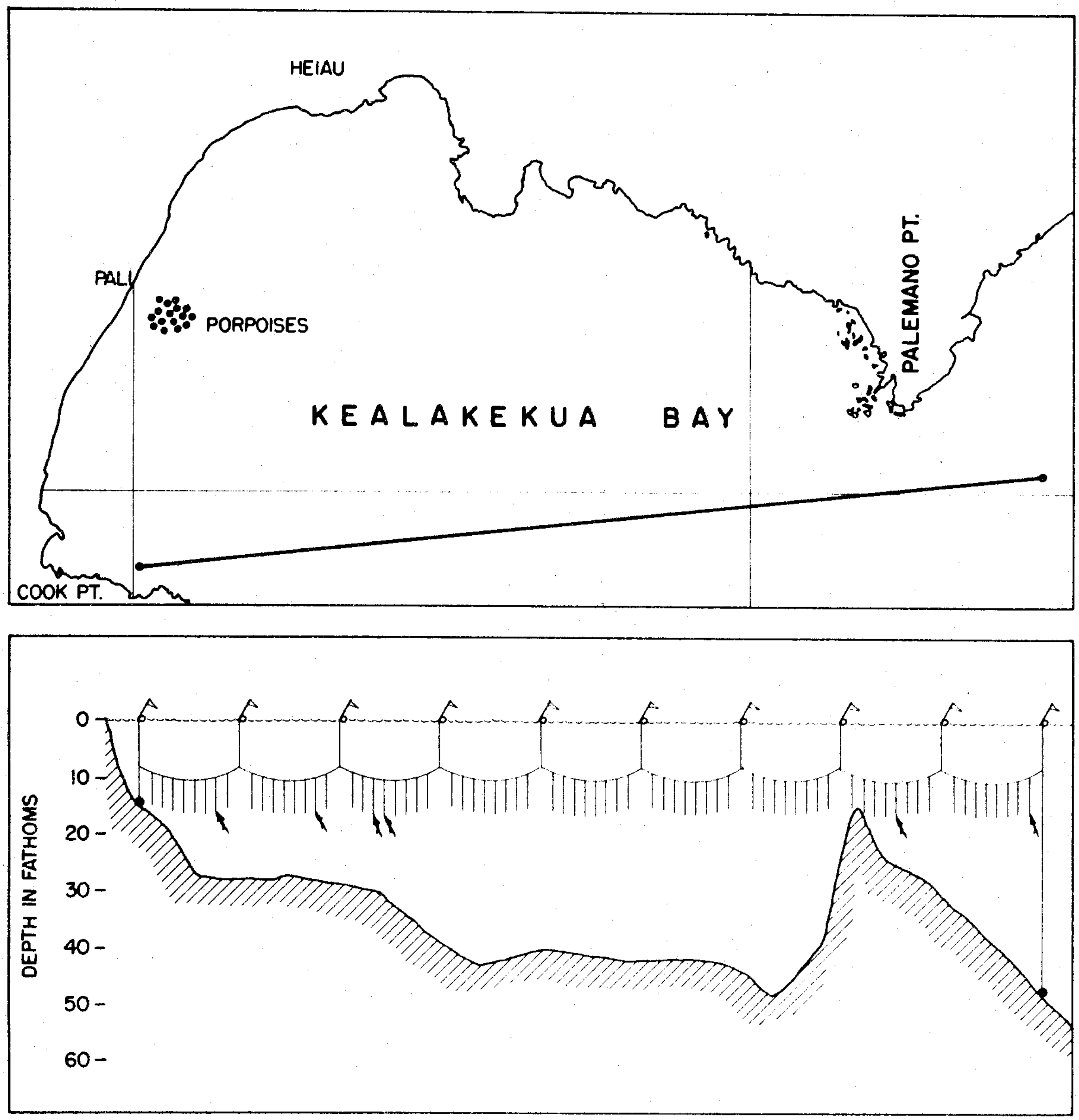
The shark population of Kealakekua Bay is moderate. Six were taken on a shark line (Figs. 36-37) stretched overnight from Cook Point southward past Palemano Point.

The shart line was set at 1700 hours, 4-XI-68. The first anchor was placed in 20 fathoms about midway between Cook's Monument and the small, sharp little point east of this (see the top of the sharp indentation of the 10 fathom line in Fig. 36 , pointing roughly at Umi's Well). Worked almost due south and heading for comparable water off Palemano Point, all baskets were tied together and a straight, continuous line of hooks was lain.

It was assumed that the hooks would hang near bottom at both ends and hang about 20 fathoms deep over the deeper water in the center of the bay. We underestimated the distance and overshot Palemano Point by quite a bit, sending the last anchor in 60 fathoms (and deepening fast) to the south of the point. Set finished at 1750 hours; surface temperature 27.3° C, temperature at 20 fathoms 26.8° C.

Began retrieving the line at 0645 the following morning. The catch was two Carcharhinus milberti, one C. galapagensis, one C. limbatus and two Galeocerdo cuvieri.

All sharks were caught in the shallower portions of the set where hooks were near bottom, or (last portion of the set) where the anchor held hooks near bottom even in deep water.



FIGURES 36-37. Line of shark set and bottom contour along a line across the mouth of Kealakekua Bay.

The *Carcharhinus galapagensis* (on hook next to a large *Galeocerdo cuvieri*) was bitten off behind the head, leaving only head plus one pectoral fin. Large shark vertebrae found in the tiger shark's stomach were much larger than the *C. galapagensis* vertebrae. (The tiger shark had eaten a different, larger shark, not the *C. galapagensis*.)

Color photos were taken of the large male *Carcharhinus limbatus*, the two *C. milberti*, and the head and pectoral of the *C. galapagensis*.

Porpoises

There is a resident school of spinner porpoises (*Stenella sp.*) in Kealakekua Bay. From 30 to 80 members were variously estimated. They are most often observed in the vicinity of Manini Beach Point, and are invariably present. One researcher worked eight consecutive days in the bay and observed them on each of the eight days.

The animals are not shy, remaining approximately in place as the research vessels move through them, a few playing in the bow-pressure wave or accompanying alongside. Often they follow the vessels for a considerable distance, yet not beyond the confines of the bay.

Several babies less than 36 inches long were observed, as well as at least five sub-groups hanging together in addition to "unattached" animals. If this school is as permanently present as reports indicate, and as tame as was observed, it would seem that it constitutes a remarkable living asset. Rarely have spinner porpoises been known to be so casual about being closely approached, and this school would seem particularly suited for experiments in semi-domestication and training in the wild, as has been proposed for resident schools elsewhere.

If there were to be a large tourist development in the area, it would be necessary to give strong attention to protecting the porpoises and keeping them "tame," but it would also provide the possibility of an extraordinary reward. There is good reason to believe that such wild animals can be trained to take dead fish, and once such a "hold" is established over them, their training to jump *en masse* on sound command, follow a particular boat in jumping trains, and so on, would be a routine matter of applying established training techniques. Such animals could also be trained to accept being held on stretchers for various physiological tests and a whole spectrum of other scientific activities. This use would not interfere with the hypothetical tourist show. For studies of social organization and interaction (N.B. the five groups thought distinguished), this school might be superior to any wild school yet known.

Turtles

Turtles were almost never seen in Kealakekua Bay by workers on this project, and no school of more than three members was sighted at all. Also noted was a dearth of "turtle algae," *i.e.*, the algal species upon which turtles are known to forage. It was concluded that turtles rarely frequent the bay.

Chapter 13

VASCULAR PLANTS

(Vegetation types of the region)

Abstract

This report describes the vegetation types which now occur in the Kealakekua Bay region. The area included in the report is that part of the Kona Coast between Keawekaheka Point north of Kealakekua Bay and Puuhonua Point at Honaunau. Fourteen vegetation types are described, and it was observed that the largest number of remnant native species occurs on the open lava flows on and mauka of Kaawaloa Flat.

Introduction

The report is based on field work conducted on 26 and 30 August, 1968. Using aerial photographs as guides, the vegetation from the Captain Cook-Napoopoo road was first surveyed. Next, the pali (Pali-o-Manuahi) by Hikiau Heiau at Napoopoo was ascended and the top explored. Afterwards, the region between Napoopoo and Honaunau and from Honaunau mauka to the Belt Road was surveyed. A boat was taken to Cook's Monument, and the area from Kaawaloa Village to Puhina-o-Lona Heiau to Keawekaheka Point was explored.

On the basis of these observations vegetation maps (Figs. 38 through 40) of the entire region were prepared using overlays on aerial photographs. Since the time available for field work was limited, no attempt was made to plot the distribution of any single species. However, a detailed may of the shoreline vegetation at Kealakekua Bay was prepared and is included (Fig. 41) in this report.

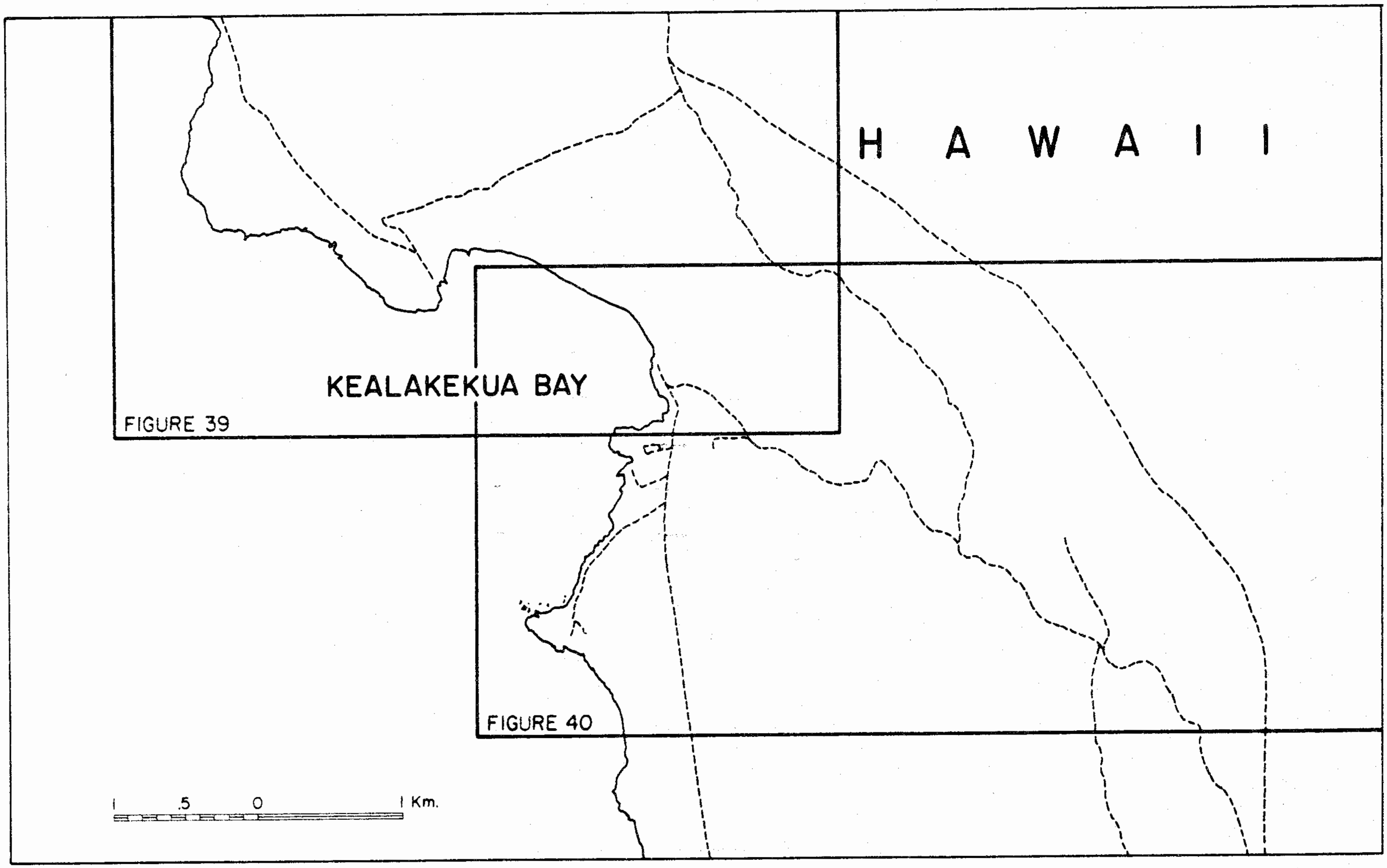


FIGURE 38. Index to Kealakekua Bay vegetation maps appearing in this report as Figures 39 and 40. Roads are shown as dashed lines.

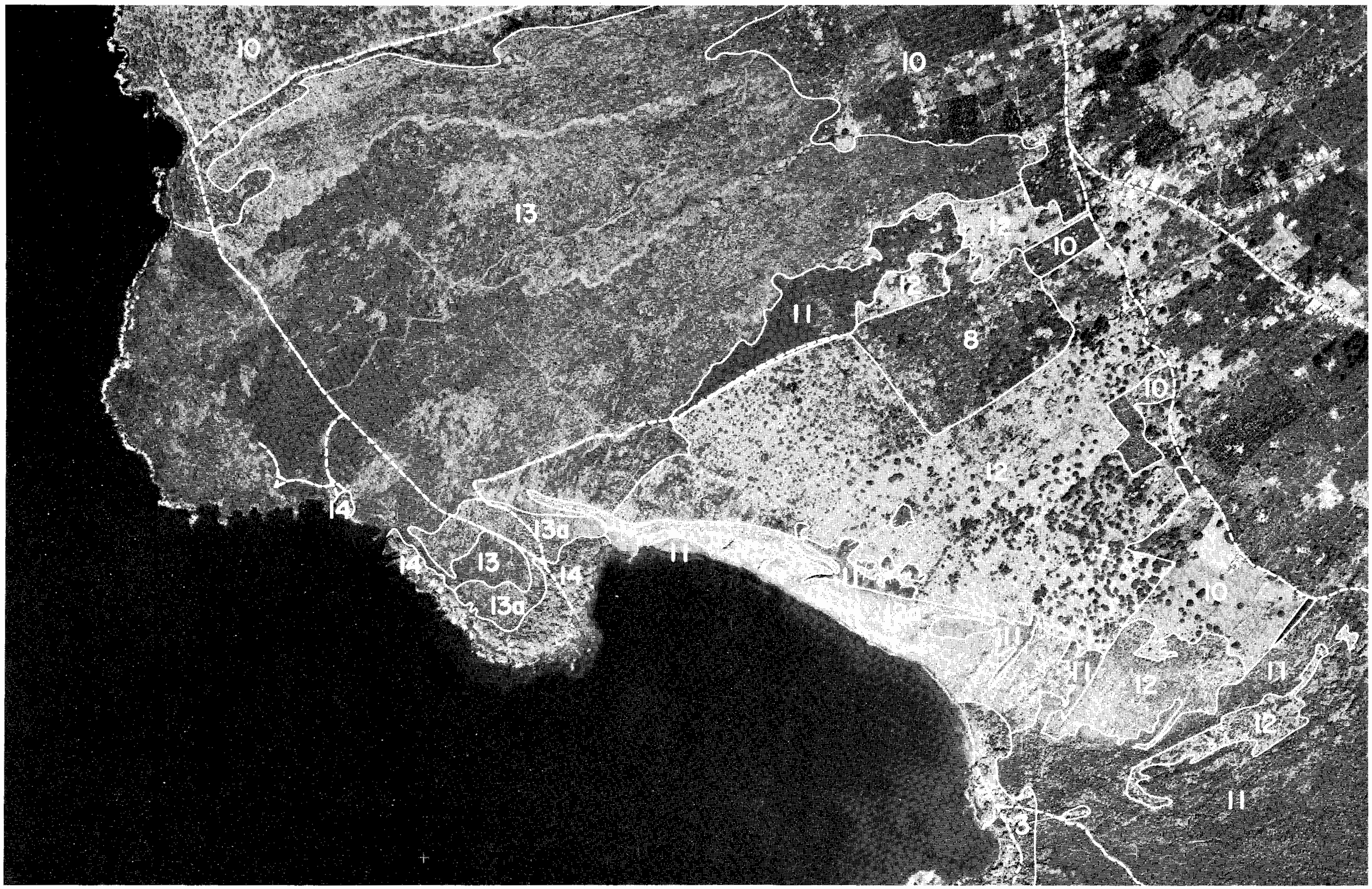


FIGURE 39. Detail of the vegetation types in the northern environs of Kealakekua Bay. The point with three 13's on it is Cook Point. Napoopoo Bay indents the shore to the right of center near the bottom margin of the figure.

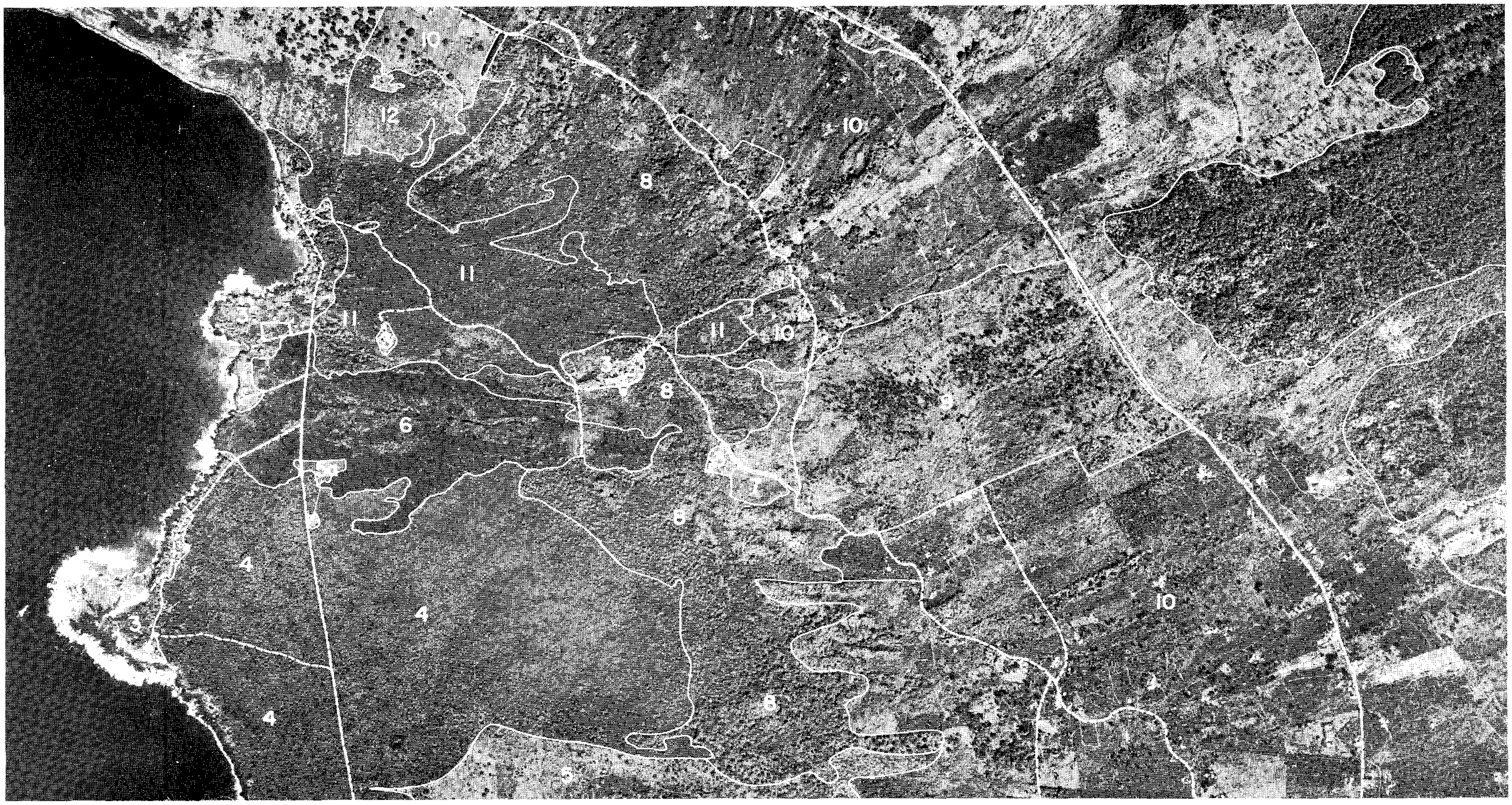


FIGURE 40. Detail of the vegetation types in the southern environs of Kealakekua Bay. Palemano Point shows protruding into the sea near the left margin below the center of the figure.

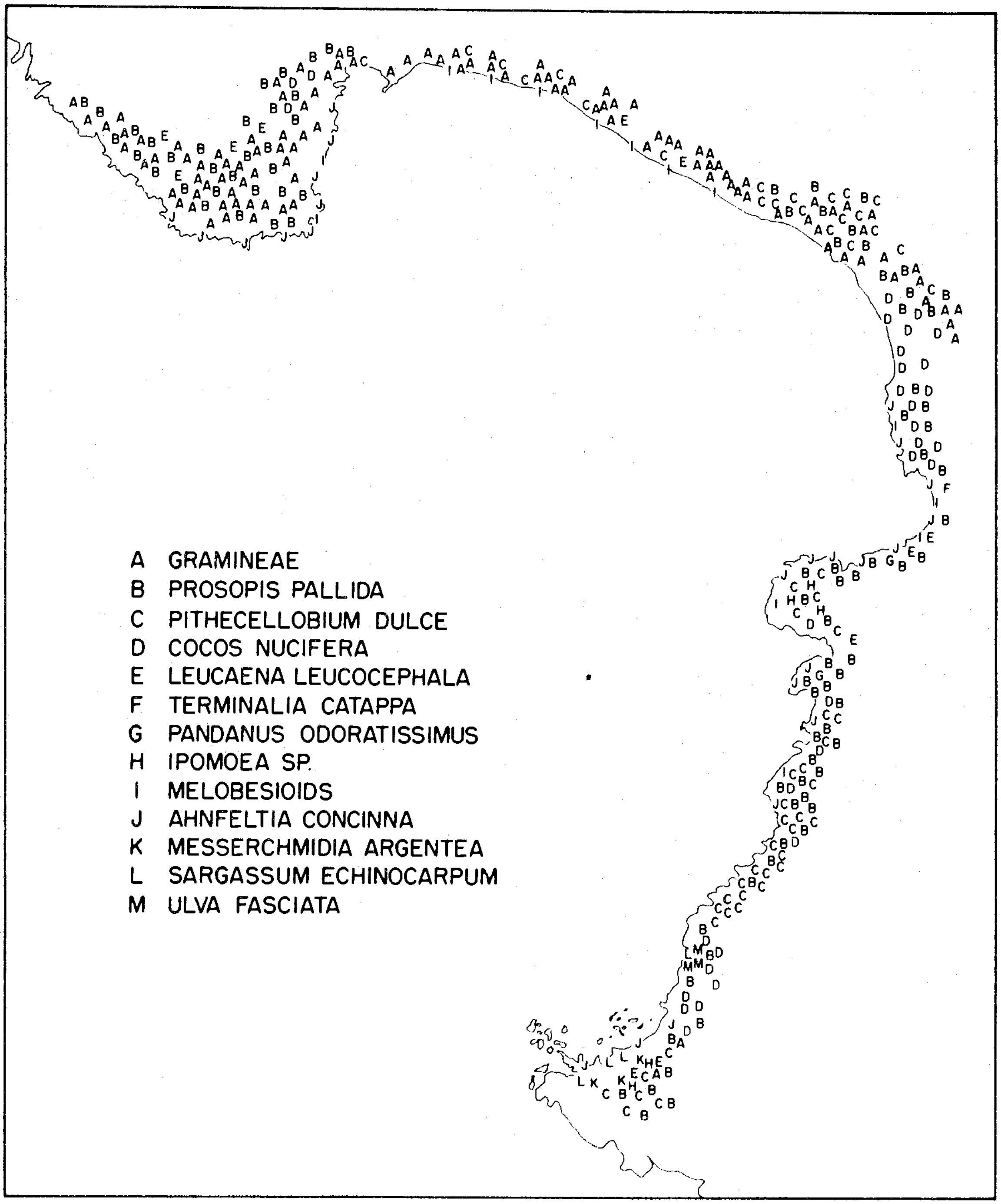


FIGURE 41. Shoreline vegetation at Kealakekua Bay.

Results

Legend for vegetation map of Kealakekua Bay region:

1. Grounds of the City of Refuge (Pu'uhonua-o-Honaunau). Vegetation consists of groves of coconuts (*Cocos nucifera*), scattered shrubs of noni (*Morinda citrifolia*), a few trees of hala (*Pandanus* sp.) and kou (*Cordia subcordata*). The sedge *Fimbristylis cymosa* grows in pockets of sand in the pahoehoe lava close to the sea and another sedge, the 'ahu 'awa (*Cyperus* sp.), grows around the brackish pools near the Great Wall. All these plants are native to Hawaii or were introduced by the Polynesians, and were undoubtedly growing here during the period that the City of Refuge was in operation. Other species, primarily weeds introduced to Hawaii since 1778, also grow here, but the National Park Service is trying to eliminate all plants which were not found in this area in Hawaiian times. A combination of manual and chemical controls is being used for this purpose, and in August 1968 recent treatment of the area with herbicides was evidenced by many dead and dying weeds.

2. Old Honaunau Village area—recently cleared. This area, until a few years ago, was covered with a scrub growth of opiuma (*Pithecellobium dulce*), koa haole (*Leucaena leucocephala*) and other species, and was probably identical with the scrub vegetation described for Type 4 (below). However, when the National Park Service acquired the land for the City of Refuge National Historical Park, they began clearing the scrub in an effort to uncover various archeological sites and to restore the vegetation to a state approaching that which was present in Hawaiian times. Consequently today this is an area of open lava with scattered plants of noni, hialoa (*Waltheria indica* L.) and other native or Polynesian-introduced species. Other, weedy, species also occur here although in fairly small numbers.

3. Residential areas. In the areas which are currently inhabited, including the villages of Honaunau and Napoopoo, one finds a wide variety of plants, mostly not native to Hawaii. Many of the species have been intentionally planted here. The more common are:

Trees: Kiawe (*Prosopis pallida*), coconut (*Cocos nucifera*), tamarind (*Tamarindus indicus*), hala (*Pandanus* sp.), kukui (*Aleurites moluccana*), monkey pod (*Samanea saman*), poinciana (*Delonix regia*), African tulip tree (*Spathodea campanulata*), false kamani (*Terminalia catappa*), date palm (*Phoenix* sp.), tree heliotrope (*Messerschmidia argentea*).

Shrubs: Hibiscus (*Hibiscus* sp.), crownflower (*Calotropis gigantea*), plumeria (*Plumeria* spp.), bougainvillea (*Bougainvillea* spp.).

Herbs: Madagascar periwinkle (*Catharanthus roseus*), air plant (*Bryophyllum pinnatum*).

Grasses: Most lawns are Bermuda grass (*Cynodon dactylon*).

4. Opiuma—koa haole scrub. This vegetation type occurs on older but relatively unweathered lava flows at elevations below about 500 feet. It covers most of the flat land between Napoopoo and Honaunau and is well represented along the road between these towns. The vegetation is dominated by large shrubs or small trees of opiuma (*Pithecellobium dulce*) and koa haole (*Leucaena leucocephala*). Among these grow shrubs of lantana (*Lantana camara*), ilima (*Sida* sp.), Christmas berry (*Schinus terebinthifolius*) and hialoa (*Waltheria indica*). Two vines which occur commonly here are a passion flower (*Passiflora foetida*) and a morning glory (*Ipomoea indica*). The sword fern (*Nephrolepis exaltata*) occurs in more open areas, occasionally covering patches of lava several meters in

diameter. Along roadsides, where finer soil particles have accumulated, other species occur which are not common on the coarser rocks. These include red top grass (*Tricholaena repens*) and air plant (*Bryophyllum pinnatum*).

The area includes many lava flows of different types, ages and degrees of weathering. The height and vigor of the vegetation vary from flow to flow. On certain flows the opiuma becomes a tree up to 25 feet high, on other flows it is a shrub not more than 10 feet high. At higher elevations other species including trees appear. This is described (#8, below) as a separate vegetation type.

5. Areas recently cleared. One large area within the opiuma-koa haole scrub has been cleared in recent years, reportedly to become a golf course. This area was not visited, but from aerial photographs it would seem that it is now primarily grassland with very scattered trees and shrubs. Two smaller areas, designated as 5a on the map, have recently been cleared along the Napoopoo-Honaunau road near Napoopoo.

6. Open lava flow. This area represents perhaps the newest lava flow in the region. It supports a very scattered growth of small opiuma (*Pithecellobium dulce*) shrubs, extensive patches of sword fern (*Nephrolepis exalta*), and scattered plants of Christmas berry (*Schinus terebinthifolius*), hialoa (*Waltheria indica*), morning glory (*Ipomoea indica*) and a small native mint (*Plectranthus australis*).

7. Plumeria plantation. This area has recently been cleared and planted with varieties of plumeria as a commercial operation.

8. Mixed forest-scrub. Mauka of the opiuma-koa haole scrub (#4) and the koa haole scrub (#11) are areas which are probably somewhat wetter and which support more trees. There is usually a gradual transition

rather than a sharp boundary between these zones. Opiuma (Pithecellobium dulce) becomes a large tree (40 ft. or more in height) in this mixed forest-scrub where several other tree species occur. The most common are: kukui (Aleurites moluccana), monkey pod (Samanea saman), mango (Mangifera indica), avocado (Persea americana) and Chinaberry (Melia azedarach). None of these is a native Hawaiian species. However, just mauka of the coffee mill and north of the plumeria plantation, on a fairly open lava flow, are several trees of ohe makai (Reynoldsia sandwicensis), a rare endemic tree, which is perhaps the botanically most interesting plant now to be found in the whole region.

9. Pastureland with remnant native forest. In one area, which is used as a pasture, there is a small remnant population of ohia lehua (Metrosideros collina). This consists of a few scattered ohia trees, mixed with kukui (Aleurites moluccana), silk oak (Grevillea robusta), octopus tree (Brassaia actinophylla), African tulip tree (Spathodea campanulata) and monkey pod (Samanea saman). These are growing in a grassland dominated by guinea grass (Panicum maximum). This may be an indication that in former times ohia forest extended down the slopes of Mauna Loa in this region to well below the level of the present belt road.

10. Cultivated areas. These include areas in which crops (primarily coffee, but some citrus, bananas and macadamia nuts) are being grown today with, additionally, small garden plots being found around the residences.

11. Koa haole scrub and forest. These areas are dominated by koa haole (Leucaena leucocephala) which occurs in nearly pure stands. Occasional plants of opiuma (Pithecellobium dulce) can be found, especially near the edges of these areas where there is a transition of the opiuma-koa haole scrub (#4). The koa haole forms closed stands with little

undergrowth except for young koa haole plants and occasional shrubs of lantana (Lantana camara). In areas which are apparently wetter (probably because they are more shaded and more protected from wind, but in some cases because of development of soil which retains more moisture) the koa haole develops into trees up to 30 feet tall. In apparently dryer areas it occurs as shrubs rarely more than 8 to 10 feet tall. Isolated patches of this scrub occur on the face of Pali-o-Manuahi and scattered in the guinea grass pasture above the pali. These are transitional areas between this type and type 12, where the koa haole plants are more widely separated and guinea grass is able to grow under them.

12. Guinea grass pasture with scattered trees. The dominant grass in this pastureland at the top of Pali-o-Manuahi is guinea grass (Panicum maximum). It is a robust grass, becoming six feet tall in most places, but occasionally reaching 12 feet. Scattered through the pasture are large trees, the most common of which are monkey pod (Samanea saman), Chinaberry (Melia azederach) and mango (Mangifera indica).

12a. Guinea grass patches. On Pali-o-Manuahi are patches of guinea grass (Panicum maximum), often mixed with red top grass (Tricholaena repens). These patches of grassland are intermixed with patches of koa haole scrub.

13. Open lava flows. This area includes the slopes north of Kealakekua Bay and most of Kaawaloa Flat except for the kiawe forest described below. The area consists of a series of lava flows, apparently of different ages. Some of these support a fairly dense scrub vegetation while on others the individual plants are widely scattered. For example, around Puhina-o-Lono Heiau lantana (Lantana camara), rattlepod (Crotalaria sp.), Christmas berry (Schinus terebinthifolius), hialoa (Waltheria indica),

indigo (Indigofera sp.), lauki (Cassia leschenaultiana), klu (Acacia farnesiana) and other shrubs, together with vines such as passion flower (Passiflora foetida) and morning glory (Ipomoea indica) cover 50% or more of the surface. The shrubs are mostly less than six feet tall. In other areas, only a few hundred yards away, less than 10% of the surface is covered with vegetation, which consists mostly of isolated plants of noni (Morinda citrifolia), puapilo (Capparis sandwichiana), puakala (Argemone glauca) and hialoa (Waltheria indica), and scattered patches of sword fern (Nephrolepis exaltata).

13a. On Kaawaloa Flat mauka of the coastal kiawe forest is an area where the scrub vegetation characteristic of the open lava flows (lantana, rattlepod, klu, etc.) is mixed with shrubs of koa haole and opiuma, forming a transitional scrub vegetation with nearly closed cover and shrubs 10 to 12 feet tall.

14. Kiawe forest. The coastal area around Cook's Monument and the old Kaawaloa village site supports a forest of kiawe trees (Prosopis pallida). The trees are 30 to 40 feet tall, and growing among them are a few coconuts (Cocos nucifera). At the landing in front of Cook's Monument are a few trees of kou (Cordia subcordata). Within the bay the kiawe trees grow down to the high tide line, but on the point to the north of the bay there is an open stretch of lava several meters in width between the kiawe forest and the high tide line. In depressions in this lava, in which sand has collected, populations of the sedge Fimbristylis cymosa may be found.

General conclusions

1. Throughout the region the vegetation consists predominantly of species introduced to Hawaii since the time of Captain Cook. With the exception of the area described in 2 (below) very few native species of plants or species introduced to Hawaii by the early Polynesians can be found. Thus, there is no compelling botanical reason for preserving the vegetation of the area in its present state.

2. The only part of the region where plants that were present in Hawaii at the time of Cook's arrival are at all common is on the open lava flows on and mauka of Kaawaloa Flat.

3. If, in connection with archeological projects, it seems desirable to re-create an area as it appeared in pre-Cook times, Kaawaloa Flat and Kaawaloa Village would seem the logical place to do this. A recreation of the pre-European scene has been undertaken at the City of Refuge with some success. However, the City of Refuge project has involved the use of herbicides, and caution should be exercised whenever large doses of herbicides are employed to avoid permanent buildups of residues in the soil, and especially to avoid runoff into Kealakekua Bay where significant ecological changes might occur. Mechanical means of weed control are preferred whenever feasible. Kaawaloa Village today is covered with a kiawe forest. The kiawe was brought to Hawaii in 1828. In 1778, Kaawaloa Village probably contained mainly coconut trees, with some kou (a few are still present near Cook's Monument), milo and noni.

4. Some of the botanically more interesting plants persisting in the region today are listed on Table 17. P indicates that the species was probably brought to Hawaii by the Polynesians; N indicates that the species is probably native to Hawaii.

TABLE 17. Some of the botanically more interesting plants persisting in the environs of Kealakekua Bay. P indicates that the species was probably brought to Hawaii by the Polynesians; N indicates that the species is probably native to Hawaii.

N or P	Scientific name	Common name	Comment
N	*Psilotum nudum*	moa	Common on open lava flows.
N	*Nephrolepis exaltata*	ni'ani'au, sword fern	Common on open lava flows.
N	*Polypodium pellucidum*	'ae	Occasional on open lava flows.
N	*Cyperus* spp.	'ehu'awa	In swampy areas around springs near the coast, *e.g.*, at Kaawaloa Village.
N	*Fimbristylis* spp.	sedge	In pockets of sand on lava flows near coast.
P	*Cocos nucifera*	niu, coconut	Scattered along coast, probably more abundant in past.
N	*Pritchardia* sp.	loulu	Soehren and Newman (1968) indicate this plant still occurs in the area. We did not find it, but did not conduct a thorough search.
N	*Peperomia leptostachya*	'ala'ala-wainui	Occasional on open lava flows.
N	*Cocculus ferrandianus*	huehue	Scattered on open lava flows.
N	*Argemone glauca*	pua kala, prickly poppy	Occasional above Kaawaloa Flat.
N	*Capparis sandwichiana*	pua pilo	Common on and above Kaawaloa Flat.
P	*Tephrosia purpurea*	'auhuhu	Occasional above Kaawaloa Flat.
N	*Waltheria indica*	hi'aloa	Common on open lava flows.

TABLE 17 (continued)

N or P	Scientific name	Common name	Comment
N	Reynoldsia sandwicensis	'ohe makai	Rare, a few trees at makai edge of plumeria plantation, and others on open lava flow just north of this.
N	Plumbago zeylanica	hilie'e	Rare, on Kaawaloa Flat.
N	Ipomoea indica	koali 'awahia, morning glory	Common throughout, on open lava and in scrub.
P	Cordia subcordata	kou	A few trees near Cook's Monument.
P	Morinda citrifolia	noni	Occasional on open lava flows and in scrub.

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Form 10-227
(April 1966)

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

RESEARCH REPORT REVIEW
(Natural Sciences)

PARK	REGION
City of Refuge National Historical Park	Western
1. Author(s) Doty, Maxwell S., Coordinator. Botany Department, U.Hawaii	2. Date of Report December 1968

3. Title of Report
BIOLOGICAL AND PHYSICAL FEATURES OF KEALAKEKUA BAY, HAWAII. Final Report. Prepared for the Office of the Lt. Governor of the State of Hawaii

4. Publication Reference
HAWAII BOTANICAL SCIENCE PAPER NO. 8 (University of Hawaii publication)

5. Brief Abstract

The conclusions of the present study of Kealakekua Bay relate to the geological and hydrological conditions and to the algae (limu), plankton, corals, molluscs (e.g., sea shells), sea urchins (vana), crustacea (e.g., lobsters, crabs, shrimp), fish, porpoises, turtles and the surrounding land mass vegetations. Ecological zones are described for both land and marine populations, and land-sea relationships are discussed in terms of the sediment and other contents of the freshwater runoff.

6. Implications of Results, or Investigator's and/or Chief Scientist's Recommendations to the Service Based Upon Report Conclusions *(Use Additional Sheets if Needed)*:

The conclusions derived from this study provide resource managers and land owners with many pertinent comments of the effects of man's activities in the area and suggestions to alleviate the undesirable elements. The ecological principles discussed in this report apply to the City of Refuge, which is located about $1\frac{1}{2}$ miles from the Bay.

7. Copies of Report and Review to:

a. Research Report File	d. ______	h. ______	Reviewed By James W. Larson
b. Park	f. ______	i. ______	Date
c. Region	g. ______	j. ______	March 14, 1969

8. Application of Research Results *(List actions or programs initiated as a result of this research, values of research to the Service, etc. Use additional sheets if needed)*:

9. RSP Number

C	I	R	E	N	-			

(SEE REVERSE FOR INSTRUCTIONS)

INSTRUCTIONS

RESEARCH REPORT REVIEW

1. When the Final Research Report is received in the Washington Office, acknowledgement is made by letter to the investigator as soon as possible.

2. A Natural Sciences staff member then reviews the report in depth, and abstracts the salient information onto this form.

3. The Chief Scientist may make recommendations, on this form, to the Service concerning the application of research results.

4. Copies of the completed form are transmitted to the park, region, and appropriate divisions at WASO. A copy of the Final Research Report is permanently retained, along with the review form, in the Natural Sciences Research Report File at WASO. Other copies of the Final Research Report are transmitted to those branches or divisions that have need for the research data, as well as to the region involved.

5. Park, region and/or other offices should notify the Division of Natural Sciences Studies in WASO of actions taken to apply these research results. The Division at WASO then makes notation of such action under item 8 on Form 10-227. This may take place at any time after the initial review has been made.